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COMPARISON OF VGH DATA FROM WIDE-BODY AND NARROW-BODY LONG-HAUL TURBINE-POWERED TRANSPORTS

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16. Abstract

Data are presented on incremental normal accelerations due to gusts, operational maneuvers, and check-flight maneuvers; on derived gust velocities; and on the airspeed and altitude operating practices of one type of wide-body, long-haul transport airplane flown by five airlines on international routes. These data are compared with VGH data obtained from long-haul, narrow-body transport airplanes also flown over international routes.

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SUMMARY

In the early 1970's, the National Aeronautics and Space Administration conducted a VGH investigation of in-flight accelerations and operational practices of wide-body long-haul turbine-powered transports. Included in the program were six aircraft of one type of wide-body transport operated by three U.S. international airlines and two foreign international airlines. The results were compared with those for the initial operations of narrow-body transports. The comparison showed that the gust and operational maneuver accelerations for the wide- and narrow-body transports agreed reasonably well, accelerations for the wide-body transports occurring somewhat less frequently. Check-flight maneuver accelerations experienced by the wide-body transports occurred less frequently, and were of a lower magnitude than those for the narrow-body transports. The maximum airspeeds experienced by the wide-body transports were generally less than the operating speed at which the overspeed warning would sound. No unusual events, such as those experienced in the early narrow-body transport operations, were noted for the wide-body transport operations.

INTRODUCTION

The NASA and its predecessor, the NACA, have been conducting VG-VGH investigations of aircraft normal accelerations and operating practices of commercial transports in routine operations since the 1930's. The programs on transports equipped with internal combustion engines and propellers were essentially complete in the late 1950's. With the advent of turbine-powered aircraft in the late 1950's, and early 1960's, the NASA initiated a program on short-haul turboprop and medium- and long-haul turbojet and turbofan aircraft. Results on these early turbine-powered transport operations were reported in references 1 to 10, some of which included fairly small samples of the available data evaluated as of the report date. Recently, however, the NASA has analyzed a more complete sample of data from these early turbine operations, particularly, of the medium- and long-haul narrow-body turbojet and turbofan transports.

In the late 1960's, and early 1970's, the wide-body long-haul turbofan transports entered commercial operations. Three types of the wide-body transports were included in the NASA VGH program. Although a reasonable sample size of data was collected on several aircraft from one type of wide-body transport, the NASA VGH programs on all wide-body transports were terminated prematurely in the early 1970's because of a change in NASA research priorities and availability of funds and personnel.

The data collected from six aircraft of the earliest type of wide-body turbofan transports flown by five airlines have recently been analyzed. The purpose of this report is to present the results of this analysis on in-flight normal accelerations and operating practices and to compare them with similar results obtained by NASA on 12 aircraft of essentially two types of narrow-body long-haul transports flown by four airlines.

SYMBOLS

Values are given in both SI and U.S. Customary Units. The measurements were made in U.S. Customary Units.

A	aspect ratio, $\frac{b^2}{S}$
a_n	incremental normal acceleration, g units
b	wing span, m (ft)
c	mean geometric wing chord, m (ft)
g	acceleration due to gravity, 9.81 m/sec^2 (32.2 ft/sec^2)
K_g	gust factor, $\frac{0.88\mu_g}{5.3 + \mu_g}$
M	Mach number
M_D	design dive Mach number
M_{MO}	maximum operating limit Mach number
m	lift-curve slope, per radian, $\frac{6A \cos \Lambda}{A + 2 \cos^2 \Lambda}\left(\frac{A + 2 \cos \Lambda}{2 \cos \Lambda + A\sqrt{1 - M^2 \cos^2 \Lambda}}\right)$

S wing area, m^2 (ft^2)

U_{de} derived gust velocity, m/sec (ft/sec)

V_B gust penetration airspeed, knots

V_D design dive airspeed, knots

V_e equivalent airspeed, m/sec (ft/sec)

V_i indicated airspeed, knots

V_{MO} maximum operating limit airspeed, knots

W airplane weight, N (lb)

Λ sweep angle of wing quarter chord, deg

μ_g airplane mass ratio, $\dfrac{2W}{m\rho cgS}$

ρ atmospheric density, kg/m^3 ($slugs/ft^3$)

ρ_o atmospheric density at sea level, kg/m^3 ($slugs/ft^3$)

AIRCRAFT AND INSTRUMENTATION

Aircraft Characteristics

Some pertinent characteristics of wide- and narrow-body long-haul transports reported on are listed in table 1. The aircraft type designation is consistent with the designation evolved in reference 1 and extended in reference 10. For the narrow-body transports, type ID differs from IC only in that the former has a turbofan whereas the latter has a turbojet engine. For the wide-body transports, type XVIIA differs from type XVII in the use of a "wet" turbofan engine and has a somewhat greater gross take-off weight.

Instrumentation

The NASA VGH recorders used on the transports were the analog type which recorded time histories of indicated airspeed (designated by V), normal acceleration

(designated by G) near the center of gravity, and pressure altitude (designated by H) on photographic paper. Detailed descriptions of the recorders and their installation and accuracy are covered in the literature (refs. 1 to 11) and, hence, will not be repeated herein.

SCOPE OF DATA

Wide-Body Transports

The scope of the data is summarized in table 2. Data were collected on six aircraft (all of type XVII, one being powered by wet turbofans and designated by type XVIIA) operated by five airlines (designated as F, M, N, P, and Q). Operators F, P, and Q were U.S. domestic international airlines, and operators M and N were foreign international airlines. The recording period covered about 3/4 to $1\frac{1}{2}$ years and the size of operational data samples was from about 700 to 2400 flight hours. The flight time spent in check flights varied from 0 to about 3 percent for operators F and N, respectively.

Narrow-Body Transports

Data were collected from 12 narrow-body long-haul transport aircraft operated by four airlines (designated as E, F, K, and L). Operators E and F were U.S. international and K and L were foreign international. Operator K had seven type ID aircraft in the program; operator E had two type IIC and one type IC; and operators F and L had one aircraft each, types IC and IIC, respectively. The recording period covered from 1 to 4 years during which time data samples of from 2000 to 16 000 flight hours were obtained. Flight time spent in check flights ranged from about 1 percent for operator L to about 6 percent for operator E. Distance flown during check flights was estimated by using the average true airspeed obtained from operational flights and the time flown on check flights.

RESULTS AND DISCUSSION

Mission Characteristics

Typical mission characteristics for operational flights of the wide-body and narrow-body transports are given in table 3. Such information is useful in defining ground-air-ground cycles, and establishing valid mission profiles.

The average flight duration and the distance traveled are about 40 and 50 percent greater, respectively, for the wide-body transports than for the narrow-body transports. Although the average cruise altitude for the wide-body transports is only 0.3 km (1200 ft) higher than that for the narrow-body transports, the wide-body transports spend more time and travel a greater distance in their climb to and descent from cruise altitude. However,

the time and distance expended in climbing to and descending from cruise altitude expressed as percent of flight time and distance is the same (22 percent in time and 16 percent in distance) for both wide- and narrow-body operations. The average true airspeed for the wide-body transports is 10 percent higher in climb, 3 percent higher in cruise, and 14 percent higher in descent than for the narrow-body transports.

Presentation of Normal Acceleration Data

Frequency distributions of the positive and negative incremental normal accelerations measured from a threshold of 0.2g for gusts, operational maneuvers, and check-flight maneuvers are presented in tables 4, 5, and 6, respectively, for wide-body transports. Distributions of the cumulative frequency of occurrence per nautical mile of incremental normal accelerations due to gusts, operational maneuvers, and check-flight maneuvers are presented in figures 1(a) to 1(c), and for the total in-flight accelerations (sum of gust, operational, and check-flight maneuvers) in figure 1(d).

The cumulative frequency of occurrence per nautical mile of gust and operational maneuver accelerations is based on the distance flown in operational flights (commercial passenger carrying flights); for check-flight maneuver accelerations and total in-flight accelerations the distance is based on the total distance flown in both check and operational flights.

Detailed information on the frequency of occurrence and the cumulative-frequency of occurrence per nautical mile of gust, maneuver, and check-flight maneuver accelerations for each operation of the narrow-body transports will not be presented. The upper and lower boundaries of these data are presented, however, in figures 2(a) to 2(d) for comparison with the boundaries for the wide-body transports. The cumulative frequency of occurrence per nautical mile of in-flight accelerations recorded for combined wide-body and for combined narrow-body operations is shown in figures 3(a) to 3(d). A comparison of acceleration sources for combined operations on wide-body and narrow-body transports is made in figures 4(a) and 4(b), respectively.

Gust Accelerations

The gust acceleration-frequency distributions, figure 1(a), are essentially symmetrical. The maximum incremental gust accelerations experienced by wide-body transports were 0.9g and -1.2g. The frequency of occurrence of gust accelerations experienced by the various operations varied by a factor of about 2 at an acceleration level of 0.2g, and by a factor of 10 at ±0.5g. For one occurrence in 2000 n. mi., the incremental gust accelerations differed by not more than 0.05g between operations, and for one occurrence in 1 000 000 n. mi., by about 0.4g. Figure 2(a) shows that the lower boundary of the data for the wide-body transports is slightly lower than the lower boundary for the narrow-body

transports, whereas the upper boundary is about midway between the upper and lower boundaries for the narrow-body transports. Figure 3(a) indicates that for the combined operations, the frequency of occurrence of gust accelerations for the narrow-body operations was higher by a factor of about 2 at the lower acceleration levels, and for a given frequency level the difference in incremental acceleration between the narrow-body and wide-body operations was 0.1g or less. The gust acceleration experience of the wide-body and narrow-body transports is therefore considered to be in close agreement.

Operational Maneuver Accelerations

Figure 1(b) shows that the maximum incremental maneuver accelerations recorded by wide-body transports were ±0.7g, and occurred at a frequency of about one per 1 000 000 n. mi. The frequency of occurrence of given incremental maneuver accelerations for the various operations varied at most by a factor of only 2. Alternately, for given frequency levels, the incremental maneuver accelerations differed by about 0.05g or less for the various operations. This experience is in marked contrast to that for the narrow-body transports, as shown in figure 2(b). Here both the upper and lower boundaries of the wide-body frequency distributions lie in the vicinity of the lower boundary for the narrow-body operations. The frequencies for the narrow-body operations differ by a factor of 4 at low-incremental maneuver accelerations, and by as much as 60 at the higher levels of accelerations. Although relatively large differences in maneuver accelerations are apparent between individual airplanes, distributions computed from the combined values for the 12 narrow-body transports compared with those from the six wide-body transports indicate small differences in magnitude and frequency of occurrence as indicated in figure 3(b). For the combined operations, the frequency of occurrence of the incremental maneuver accelerations was higher by factors of from 2 to 6 for the narrow-body transports than for the wide-body transports. For given frequencies of occurrence, the maneuver accelerations for the narrow-body transports were from 0.05g to 0.10g higher. The operational maneuver accelerations for the wide-body and narrow body operations are therefore considered to be in reasonable agreement.

Check-Flight Maneuver Accelerations

The maximum incremental accelerations experienced in check-flight maneuvers by wide-body transports were -0.7g and 0.9g (fig. 1(c)), which are only slightly greater than those experienced during operational maneuvers. The cumulative frequency of occurrence of the incremental accelerations varied by a factor of from 4 to 20 between the various operations. The upper and lower boundaries of the data are well within those boundaries for narrow-body operations (fig. 2(c)), which differed in frequency of occurrence by as much as two orders of magnitude. The larger spread in the narrow-body data may be

due to the greater time spent in check flights, 615.6 hours compared with 113.6 hours. Figure 3(c) shows that if the check-flight maneuver accelerations from the narrow-body transports are combined into one distribution and compared with a similar distribution for wide-body transports, the frequency of occurrence of accelerations for the combined data of the narrow-body transports is higher by a factor of 2 to 3 at positive accelerations, and by as much as an order of magnitude at negative accelerations. The maximum incremental accelerations are also higher for the narrow-body operations, -1.2g compared with -0.7g, and 1.2g compared with 0.9g. It therefore appears from the data samples compared that check-flight maneuver accelerations for the wide-body transports are experienced less frequently and are of a lower magnitude than those experienced by the narrow-body transports.

Total Acceleration

The cumulative frequency of occurrence per nautical mile of the total in-flight accelerations (sum of gust, maneuver, and check-flight maneuvers) for the wide-body transports is shown in figure 1(d). The difference in frequency of occurrence of the accelerations for the various operations varies from a factor of about 2 at the low accelerations to a factor of 25 at the high accelerations. Comparison of the data boundaries in figure 2(d) shows that the lower limits are in close agreement. The upper limit for the wide-body operations lies about midway between the upper and lower boundaries for the narrow-body operations. The frequencies of occurrence for the combined acceleration data of the narrow-body transports (fig. 3(d)) are higher than those for the wide-body transports by a factor of about 5 and therefore are considered to be in relatively close agreement.

Acceleration Sources

The relative severity of the various in-flight acceleration sources experienced by the wide-body and narrow-body transports is shown in figures 4(a) and 4(b), respectively. A comparison of the data in figure 4(a) with those in figure 4(b) indicates the relative severity of the various accelerations were generally similar for the two types of transports. For the wide-body operations (fig. 4(a)) negative accelerations occurred more frequently for gusts, less frequently for operational maneuvers, and least frequently for check-flight maneuvers. Positive accelerations occurred most frequently for operational maneuvers up to about 0.4g; from 0.4g to 0.7g accelerations from check-flight maneuvers were the most frequent; and from 0.7g to 0.9g gust accelerations occurred more frequently.

For the narrow-body operations (fig. 4(b)), negative accelerations were experienced more frequently from gusts, although from -0.2g to -0.5g little differences existed

between the frequency of occurrence of gusts, operational maneuvers, or check-flight maneuvers. From -0.5g to -1.2g the second most frequent acceleration source was check-flight maneuvers, and the least frequent was operational maneuvers.

Positive accelerations resulting from operational maneuvers occurred most frequently from 0.2g to 0.4g, although as with the negative accelerations, differences between the frequency of occurrence of operational maneuvers, check-flight maneuvers, or gust accelerations in this acceleration interval were not significant. Above 0.4g, check-flight accelerations were experienced most frequently, followed by gusts, and then by operational maneuvers.

Gust Velocities

The derived gust velocity U_{de} was calculated for each gust acceleration peak by means of the equation (from ref. 12)

$$U_{de} = \frac{2Wa_n}{K_g \rho_o mSV_e}$$

Airplane weight W was computed from relations established from take-off weight provided by some airlines, flight duration, and fuel consumption. The slope of the lift curve m was computed by using the equation

$$m = \frac{6A \cos \Lambda}{A + 2 \cos^2 \Lambda}\left(\frac{A + 2 \cos \Lambda}{2 \cos \Lambda + A\sqrt{1 - M^2 \cos^2 \Lambda}}\right)$$

The frequency distribution of derived gust velocities for the various wide-body operations is given in table 7. The maximum gust velocities recorded were about -16 m/sec (-52 ft/sec) and 13 m/sec (44 ft/sec). Because the frequency distributions of positive and negative gust velocities were nearly symmetrical, the cumulative frequency of occurrence per nautical mile was determined for the combined positive and negative gust velocities within given gust velocity intervals, and is shown in figure 5. The variation in the frequency of occurrence of the derived gust velocities between the different operations varied from 2 to 10 over the range of gust velocities experienced. The upper and lower boundaries of these data are well within the boundaries for the narrow-body operations, as shown in figure 6. The cumulative frequency of occurrence per nautical mile of the derived gust velocities (fig. 7) for the combined wide-body and combined narrow-body operations indicates that the gust environment was essentially the same for the two types of operations.

Airspeed Practices

The minimum, average, and maximum values of indicated airspeed, and their corresponding altitudes, recorded within 1.6 km (5000 ft) altitude intervals by the wide-body transports during operational flights are shown in figure 8. Also shown in figure 8 are the gust penetration speed V_B, the maximum operating speed V_{MO}, the speed at which the overspeed warning is sounded V_{MO} + 6 knots, the design dive speed V_D, the maximum operating Mach number M_{MO}, and the design dive Mach number M_D. The maximum operating speed V_{MO} was corrected for the static-pressure error of the static source from information supplied by the manufacturer. The minimum-indicated airspeeds (fig. 8(a)) show appreciable scatter but are within a band of about 30 knots for the various operations. The minimum airspeeds are well below the gust penetration speed V_B and vary from 125 knots (the lower cutoff level in the data evaluation) near sea level to about 240 knots at 12 km (40 000 ft). The average-indicated airspeed (fig. 8(b)) is lower than the gust penetration speed V_B below about 3.5 km (12 000 ft) and above about 10 km (33 000 ft). The peak average airspeed occurs at about 7.5 km (25 000 ft) and has a value of about 330 knots for four operations and about 310 knots for the fifth. The maximum airspeed experienced (fig. 8(c)) is conservative since the speeds are generally below V_{MO} + 6 knots, where the overspeed warning would sound. For these initial wide-body operations, the maximum airspeed experience is in marked contrast to that of the initial operations of narrow-body transports (ref. 1), which showed that the normal operating speed placard V_{NO} was frequently exceeded by large margins and the never-exceed speed placard V_{NE} was occasionally exceeded. Because V_{NO} and V_{NE} were a source of confusion and subject to misinterpretation, V_{NO} has since been replaced by V_{MO}, and V_{NE} has been eliminated.

Attention is directed to the high maximum airspeed experienced below 3.0 km (10 000 ft). These speeds far exceed the maximum speed of 250 knots prescribed by Federal Air Regulations (FAR) 91.70. In this respect, the wide-body transport experience is similar to that of the narrow-body transports. (See ref. 1, pp. 85-93.) It should be remembered, however, that these operations are generally international in scope and involve departures from and arrival at foreign terminal areas where FAR 91.70, or its equivalent, may not be in effect. The percent of time below altitudes of 3 km (10 000 ft) and above airspeeds of 250 knots in climb and descent is shown in figure 9 for various wide-body operations. The two foreign operators (M and N) spent the greatest percentage of time at speeds above 250 knots, 57 and 40 percent, respectively, in climb, and 20 and 16 percent, respectively, in descent. The U.S. operators (F, P, and O) spent 36, 25, and 22 percent, respectively, above 250 knots in climb, and 11, 15, and 9 percent, respectively, in descent.

Unusual Events

For the initial operations of narrow-body transports, a number of unusual events were noted. (See ref. 1, pp. 139-149.) These events involved oscillations due to malfunctioning autopilots, dives due to malfunctioning Mach trim, pitchup at higher altitude due to an overweight condition, oscillations due to control problems, and others. For the initial operations of the wide-body transports, no unusual events were noted in the sample of data recorded.

CONCLUDING REMARKS

In the early 1970's, the NASA conducted a VGH investigation of in-flight accelerations and operational practices on wide-body long-haul turbine-powered transports. Included in the program were six aircraft of one type of wide-body transport operated by three U.S. international airlines and two foreign international airlines. The results of this investigation were compared with the results of a similar investigation of the initial operations of narrow-body transports. The comparison showed that the gust and operational maneuver accelerations for the wide-body and narrow-body transports agreed reasonably close, those for the wide-body transports being of somewhat lower frequency. Check-flight maneuver accelerations experienced by the wide-body transports occurred less frequently and were of a lower magnitude than those for the narrow-body transports. The maximum airspeed experienced by the wide-body transports was generally less than the maximum operating speed placard V_{MO} plus 6 knots. Below an altitude of 3 km (10 000 ft), however, 250 knots (prescribed as a maximum speed by Federal Air Regulations 91.70) was exceeded a large percentage of the time. No unusual events, such as those experienced in the early narrow-body transport operations, were noted for the wide-body transport operations.

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TABLE 1.- WIDE-BODY AND NARROW-BODY TRANSPORT CHARACTERISTICS

Characteristics	Aircraft type				
	Narrow body			Wide body	
	IC	ID	IIC	XVII	XVIIA
Span, m (ft)	43.41 (142.42)	43.41 (142.42)	42.39 (142.36)	59.66 (195.67)	59.66 (195.67)
Aspect ratio	7.01	7.01	7.32	6.96	6.96
Mean geometric chord, m (ft)	6.19 (20.31)	6.19 (20.31)	5.93 (19.46)	8.57 (28.11)	8.57 (28.11)
Wing area, m^2 (ft^2)	268.7 (2892)	268.7 (2892)	257.4 (2771)	511.2 (5500)	511.2 (5500)
Wing sweep (c/4), deg	35	35	30	37.5	37.5
Maximum take-off weight, N (lb)	1 387 845 (312 000)	1 387 845 (312 000)	1 378 949 (310 000)	3 158 238 (710 000)	3 266 944 (735 000)
Maximum landing weight, N (lb)	920 782 (207 000)	920 782 (207 000)	887 420 (199 500)	2 508 796 (564 000)	2 508 796 (564 000)
Wing loading:					
Maximum take-off weight/Wing area, N/m^2 (lb/ft^2)	5166 (107.9)	5166 (107.9)	5358 (111.9)	6182 (129.1)	6391 (133.6)
Type engine	Turbojet	Turbofan	Turbojet	Turbofan	Wet turbofan

TABLE 2.- SCOPE OF DATA

(a) Wide-body transports

	Operation					Total all operations
	FXVII	MXVII	NXVIIA	PXVII	QXVII	
Recording period	Aug. 1970 to Feb. 1972	Aug. 1970 to June 1971	Nov. 1971 to Oct. 1972	Jan. 1971 to Oct. 1971	Mar. 1971 to June 1972	
Number of aircraft	2	1	1	1	1	6
Route	Circumglobal	Transpacific	Circumglobal	U.S. and Pacific	U.S. and transpacific	
Operational flights						
Number of flights	282	232	565	390	180	1649
Flight hours	1506.2	1455.0	2381.0	1391.4	715.0	7438
Distance flown, n. mi.	702 272	687 391	1 103 140	643 895	322 895	3 459 593
Check flights						
Number of flights	0	32	85	51	18	186
Flight hours	0	18.9	69.0	13.5	12.2	113.6
Distance flown, n. mi.	0	4296	12 473	2027	3030	22 626

TABLE 2.- Concluded

(b) Narrow-body transports

	Operation					Total all operations
	EIC	FIC	KID	EIIC	LIIC	
Recording period	Jan. 1960 to Mar. 1964	Mar. 1960 to Apr. 1962	Aug. 1960 to Aug. 1964	June 1960 to Mar. 1962	Apr. 1963 to Apr. 1964	
Number of aircraft	1	1	7	2	1	12
Route	Circumglobal	Circumglobal	Circumglobal	Circumglobal	Transatlantic	
Operational flights						
Number of flights	865	616	4756	945	922	8104
Flight hours	2830.7	2094.2	16 251.9	2572.9	3108.7	26 854.4
Distance flown, n. mi. . .	1 262 398	938 943	7 143 645	1 127 026	1 348 838	11 820 850
Check flights						
Number of flights	296	91	871	87	131	1476
Flight hours	167.0	37.4	308.5	72.4	30.3	615.6
Distance flown, n. mi. . .	74 777	16 777	135 432	31 693	13 147	271 826

TABLE 3.- AVERAGE OPERATIONAL MISSION CHARACTERISTICS

[Time is rounded to nearest 0.01 hr; distance is rounded to nearest nautical mile; and airspeed is rounded to nearest knot]

Flight condition and average characteristics	Narrow-body operations						Wide-body operations					
	EIC	FIC	KID	EIIC	LIIC	Av	FXVII	MXVII	NXVIIA	PXVII	QXVII	Av
Climb												
Time, hr/flight	0.30	0.29	0.31	0.35	0.35	0.30	0.59	0.59	0.53	0.46	0.47	0.53
Distance, n. mi./flight	106	103	106	90	135	108	237	242	206	179	175	208
True airspeed, knots	360	358	341	352	384	359	403	411	392	390	376	394
Cruise												
Time, hr/flight	2.58	2.66	2.66	2.08	2.61	2.52	4.15	5.17	3.31	2.64	3.00	3.65
Distance, n. mi./flight	1236	1274	1268	944	1208	1196	2040	2555	1630	1299	1451	1795
Cruise altitude, km	9.72	10.36	10.49	9.30	10.33	10.04	10.63	10.04	9.91	10.75	10.57	10.38
Cruise altitude, ft	31 900	34 000	34 400	30 500	33 900	32 900	34 900	32 900	32 500	35 000	34 700	34 100
True airspeed, knots	479	478	477	478	462	475	492	494	492	492	484	491
Descent												
Time, hr/flight	0.40	0.45	0.45	0.39	0.40	0.42	0.60	0.51	0.37	0.47	0.51	0.49
Distance, n. mi./flight	117	147	128	109	120	124	214	166	116	173	167	167
True airspeed, knots	296	329	284	281	296	297	354	326	309	371	331	338
Overall												
Time, hr/flight	3.27	3.40	3.42	2.72	3.37	3.24	5.34	6.27	4.21	3.57	3.97	4.67
Distance, n. mi./flight	1459	1524	1502	1193	1463	1428	2490	2963	1952	1651	1794	2170
True airspeed, knots	446	448	439	439	434	441	466	472	463	463	451	463

TABLE 4.- FREQUENCY DISTRIBUTION OF INCREMENTAL NORMAL ACCELERATIONS DUE TO GUSTS FOR WIDE-BODY TRANSPORTS

Acceleration interval, a_n, g units	Frequency for -				
	FXVII	MXVII	NXVIIA	PXVII	QXVII
-1.3 to -1.2			1		
-1.2 to -1.1			0		
-1.1 to -1.0			0		
-1.0 to -.9			0		
-.9 to -.8			1		
-.8 to -.7	1		0		
-.7 to -.6	0		2	1	1
-.6 to -.5	0	3	10	0	0
-.5 to -.4	12	21	38	6	12
-.4 to -.3	49	95	130	34	55
-.3 to -.2	352	565	509	286	184
.2 to .3	386	726	544	318	258
.3 to .4	43	89	117	32	55
.4 to .5	6	14	26	2	5
.5 to .6	1	6	11	1	0
.6 to .7	1	1	3		1
.7 to .8		1	2		
.8 to .9		0	3		
.9 to 1.0		1			

TABLE 5.- FREQUENCY DISTRIBUTION OF INCREMENTAL NORMAL ACCELERATIONS DUE TO OPERATIONAL FLIGHT MANEUVERS FOR WIDE-BODY TRANSPORTS

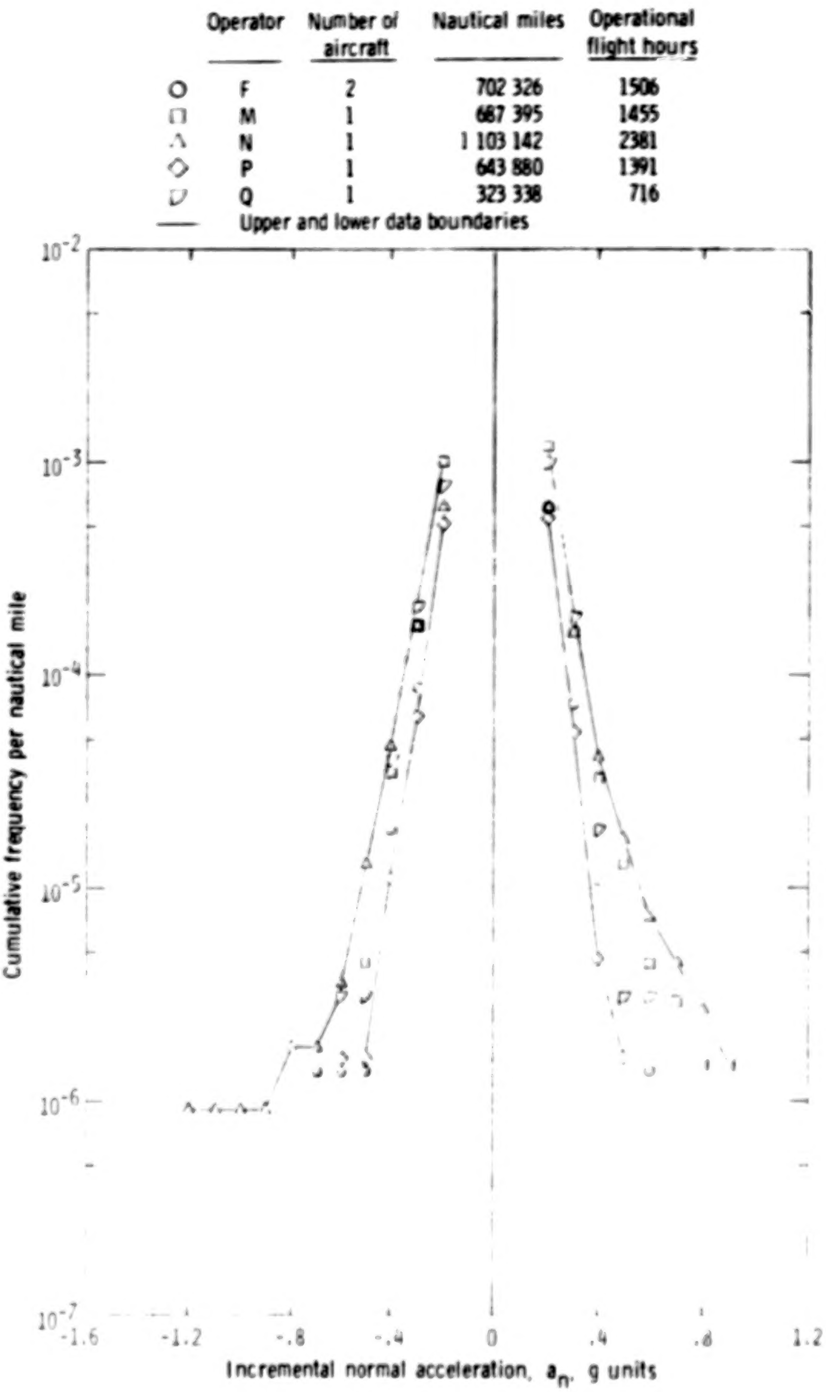
Acceleration interval, a_n, g units	Frequency for -				
	FXVII	MXVII	NXVIIA	PXVII	QXVII
-0.7 to -0.6			1		
-.6 to -.5	2		3	1	1
-.5 to -.4	2	4	13	7	3
-.4 to -.3	31	28	99	33	26
-.3 to -.2	218	229	471	344	175
.2 to .3	757	717	2401	866	405
.3 to .4	89	89	288	180	44
.4 to .5	16	16	43	22	4
.5 to .6	4	5	6	2	1
.6 to .7			5	2	2
.7 to .8				1	

TABLE 6.- FREQUENCY DISTRIBUTION OF INCREMENTAL NORMAL ACCELERATION DUE TO CHECK-FLIGHT MANEUVERS FOR WIDE-BODY TRANSPORTS

Acceleration interval, a_n, g units	Frequency for -				
	FXVII	MXVII	NXVIIA	PXVII	QXVII
-0.8 to -0.7			1		
-.7 to -.6			0		
-.6 to -.5			2		
-.5 to -.4			3		
-.4 to -.3		9	56	5	5
-.3 to -.2		66	338	78	22
.2 to .3		106	967	173	80
.3 to .4		37	303	37	14
.4 to .5		24	50	8	2
.5 to .6		16	7	4	1
.6 to .7		14	2	0	1
.7 to .8		6		1	
.8 to .9		0			
.9 to 1.0		1			

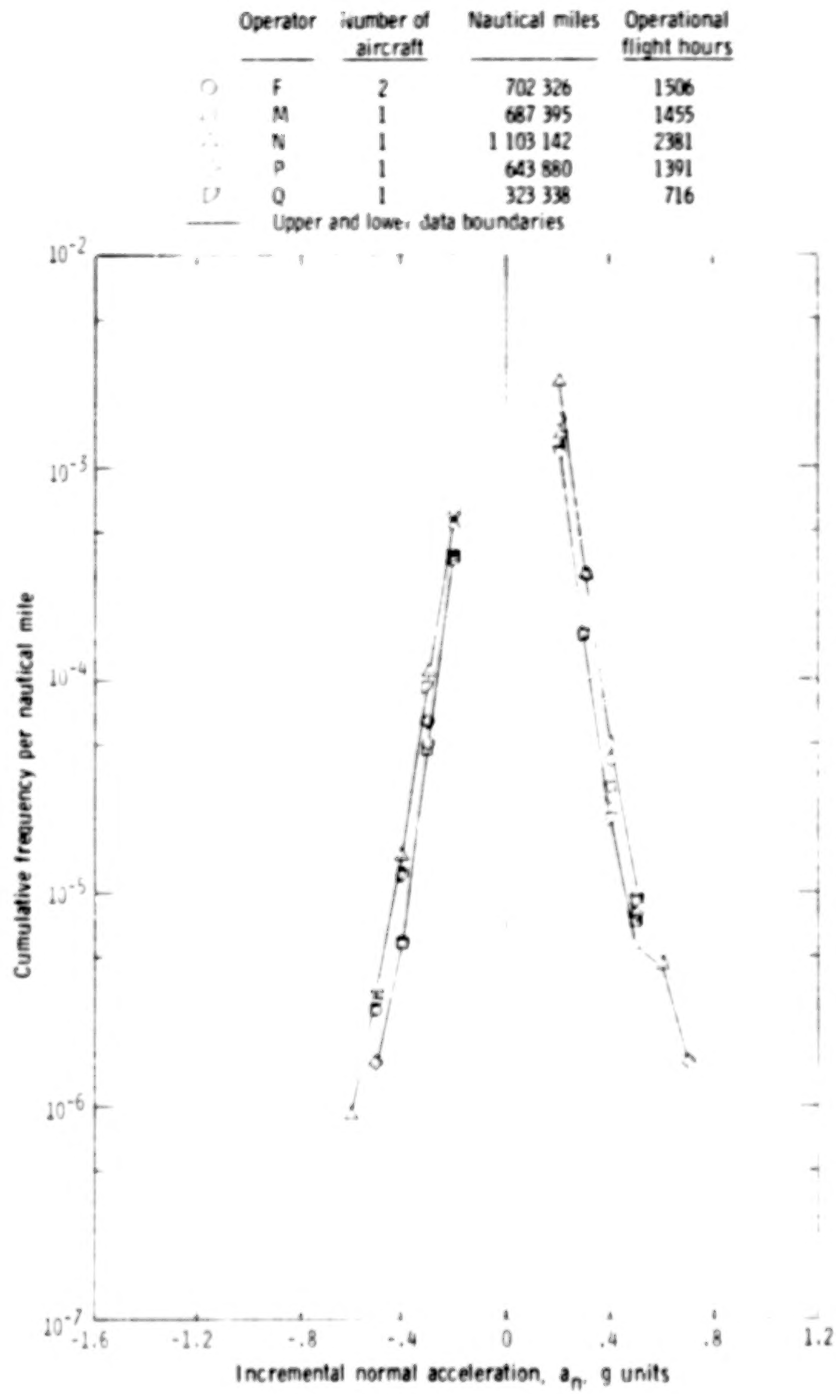
TABLE 7.- FREQUENCY DISTRIBUTION OF GUST VELOCITIES U_{de} FOR WIDE-BODY TRANSPORTS

Gust velocity interval -		Frequency for -				
m/sec	ft/sec	FXVII	MXVII	NXVIIA	PXVII	QXVII
-17.1 to -15.9	-56 to -52			1		
-15.9 to -14.6	-52 to -48			0		
-14.6 to -13.4	-48 to -44			0		
-13.4 to -12.2	-44 to -40			0		
-12.2 to -11.0	-40 to -36	1		0		
-11.0 to -9.8	-36 to -32	0		2		
-9.8 to -8.5	-32 to -28	1		3		
-8.5 to -7.3	-28 to -24	3	1	16	3	5
-7.3 to -6.1	-24 to -20	12	12	37	9	5
-6.1 to -4.9	-20 to -16	25	35	87	18	23
-4.9 to -3.7	-16 to -12	83	146	213	61	74
-3.7 to -2.4	-12 to -8	279	453	327	200	141
2.4 to 3.7	8 to 12	276	592	331	218	178
3.7 to 4.9	12 to 16	87	142	230	55	100
4.9 to 6.1	16 to 20	35	30	78	18	30
6.1 to 7.3	20 to 24	8	12	34	10	6
7.3 to 8.5	24 to 28	3	6	7	2	2
8.5 to 9.8	28 to 32	1	2	4	1	
9.8 to 11.0	32 to 36	1	0	4		
11.0 to 12.2	36 to 40		1	2		
12.2 to 13.4	40 to 44		0			
13.4 to 14.6	44 to 48		1			



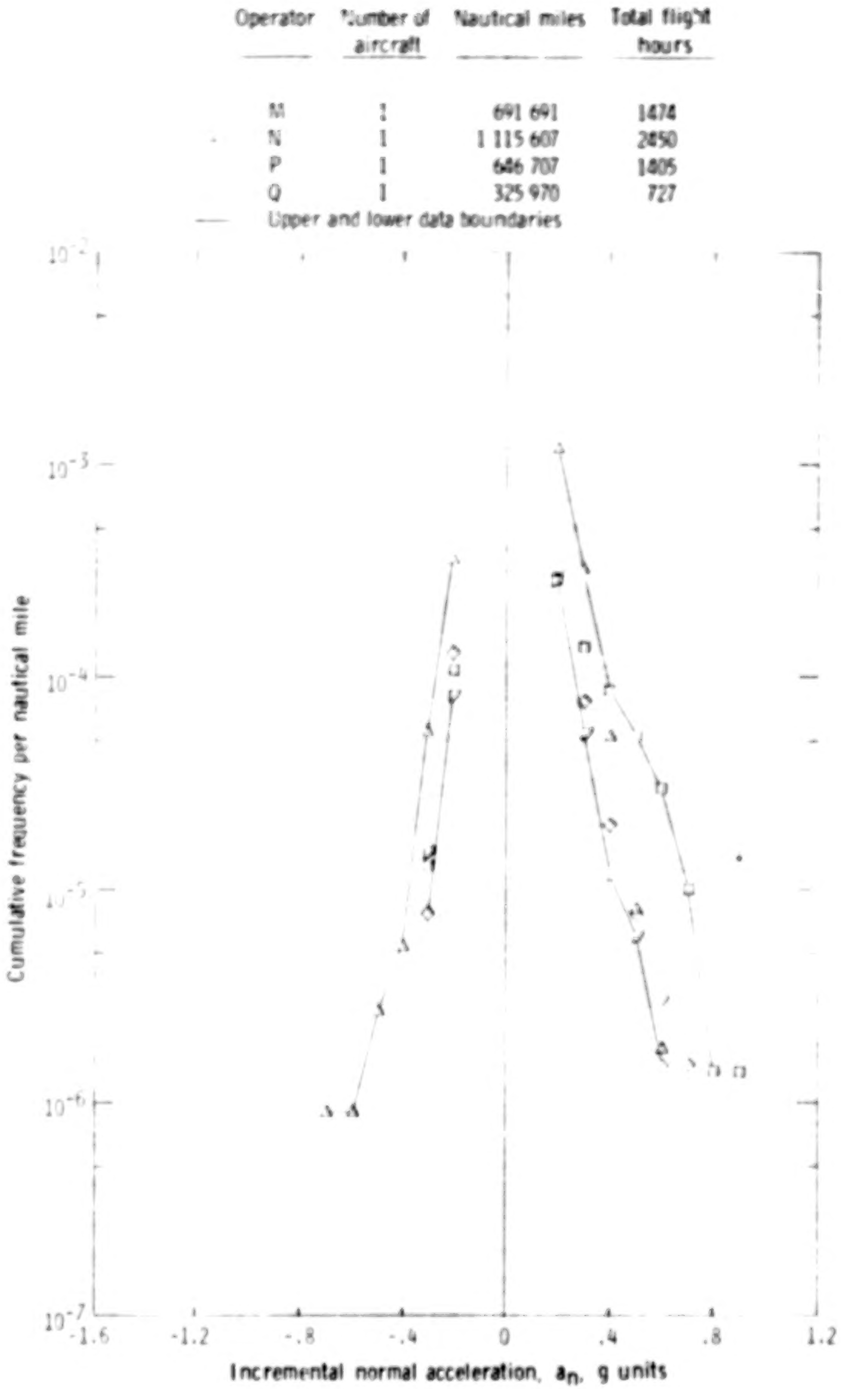
(a) Gust accelerations.

Figure 1.- In-flight acceleration experience of one type of wide-body, long-haul jet transport flown on international operations by three United States and two foreign operators.



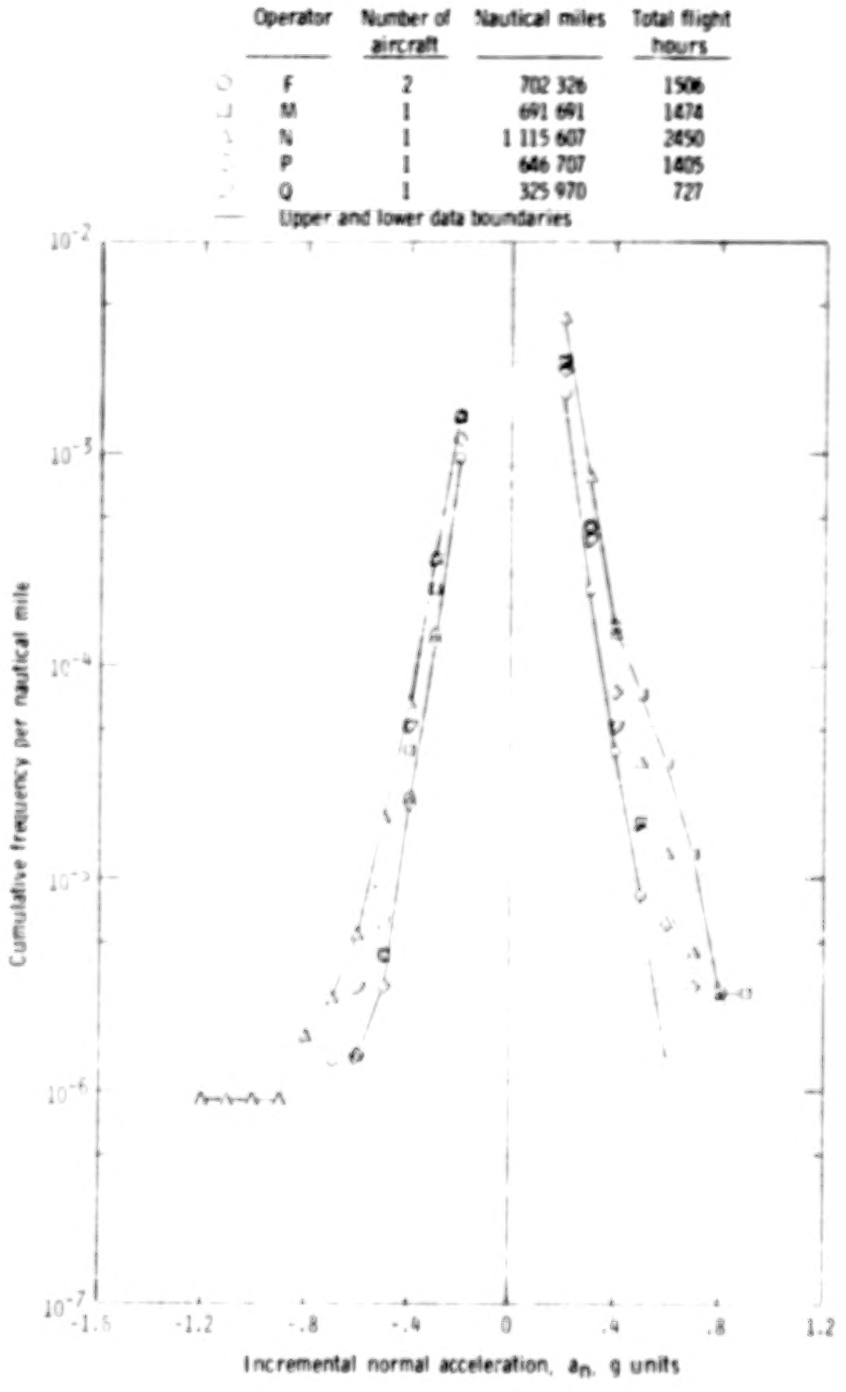
(b) Operational maneuver accelerations.

Figure 1.- Continued.



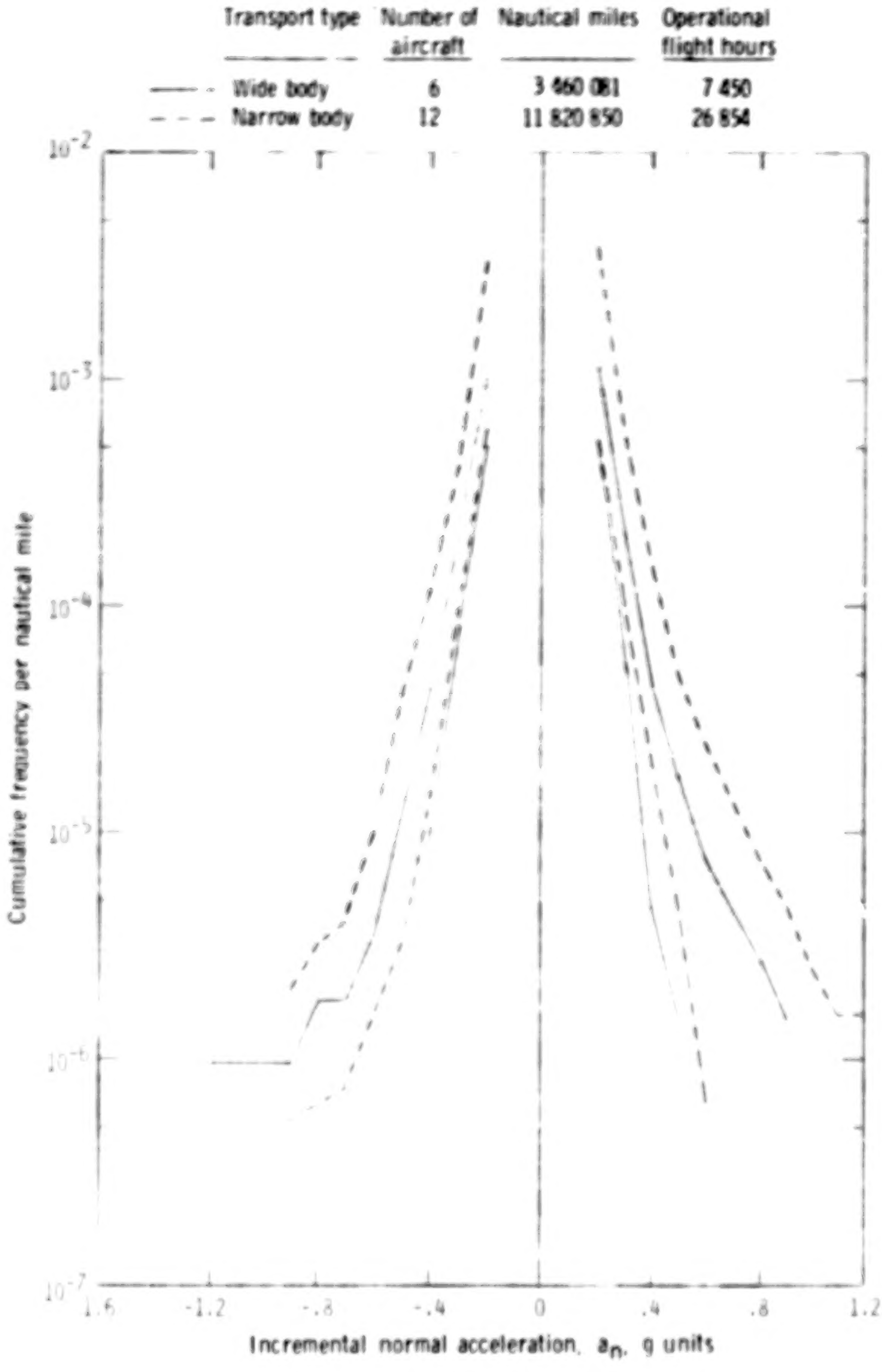
(c) Check-flight maneuver accelerations.

Figure 1.- Continued.



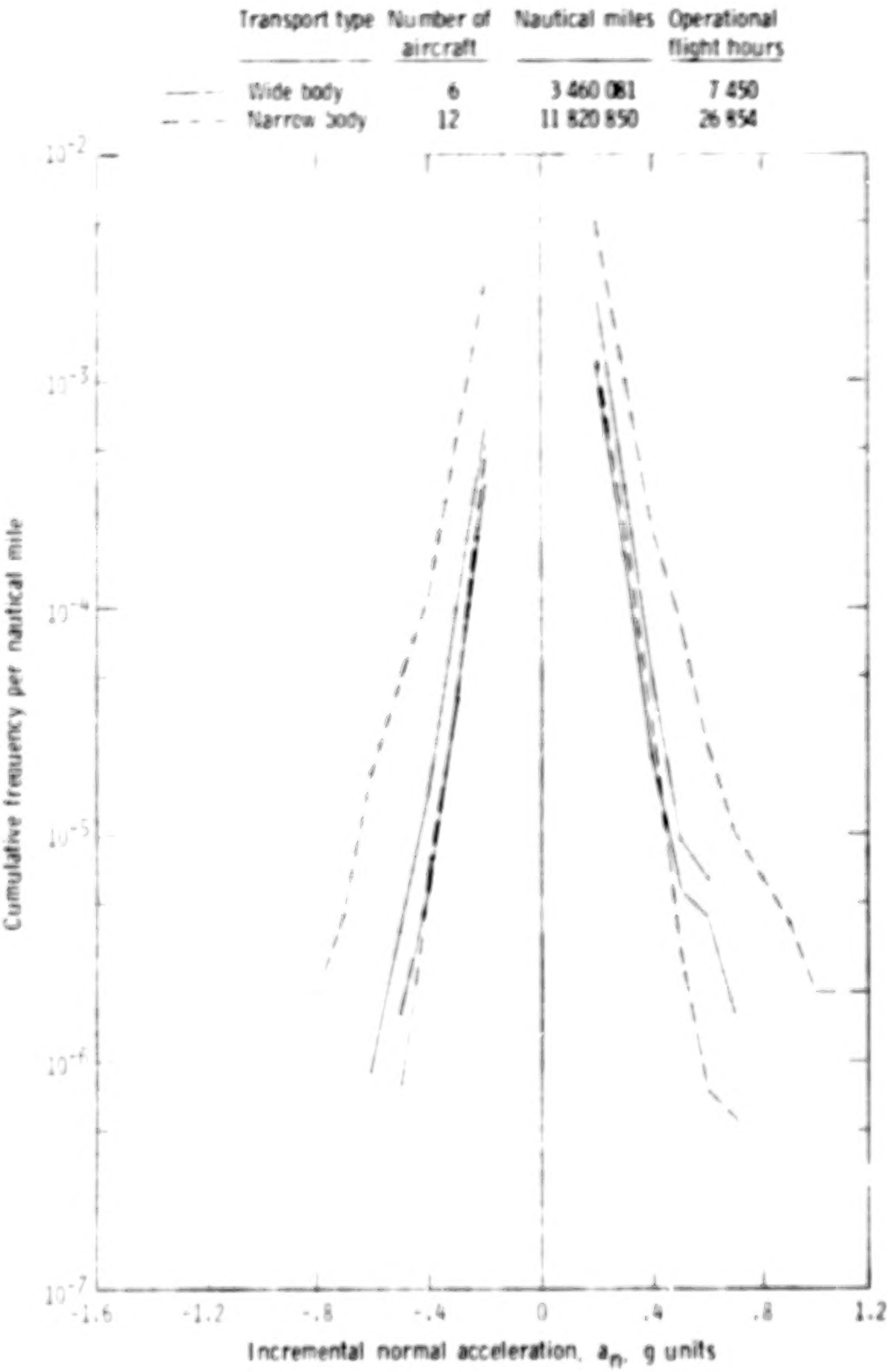
(d) Total in-flight accelerations.

Figure 1.- Concluded.



(a) Gust accelerations.

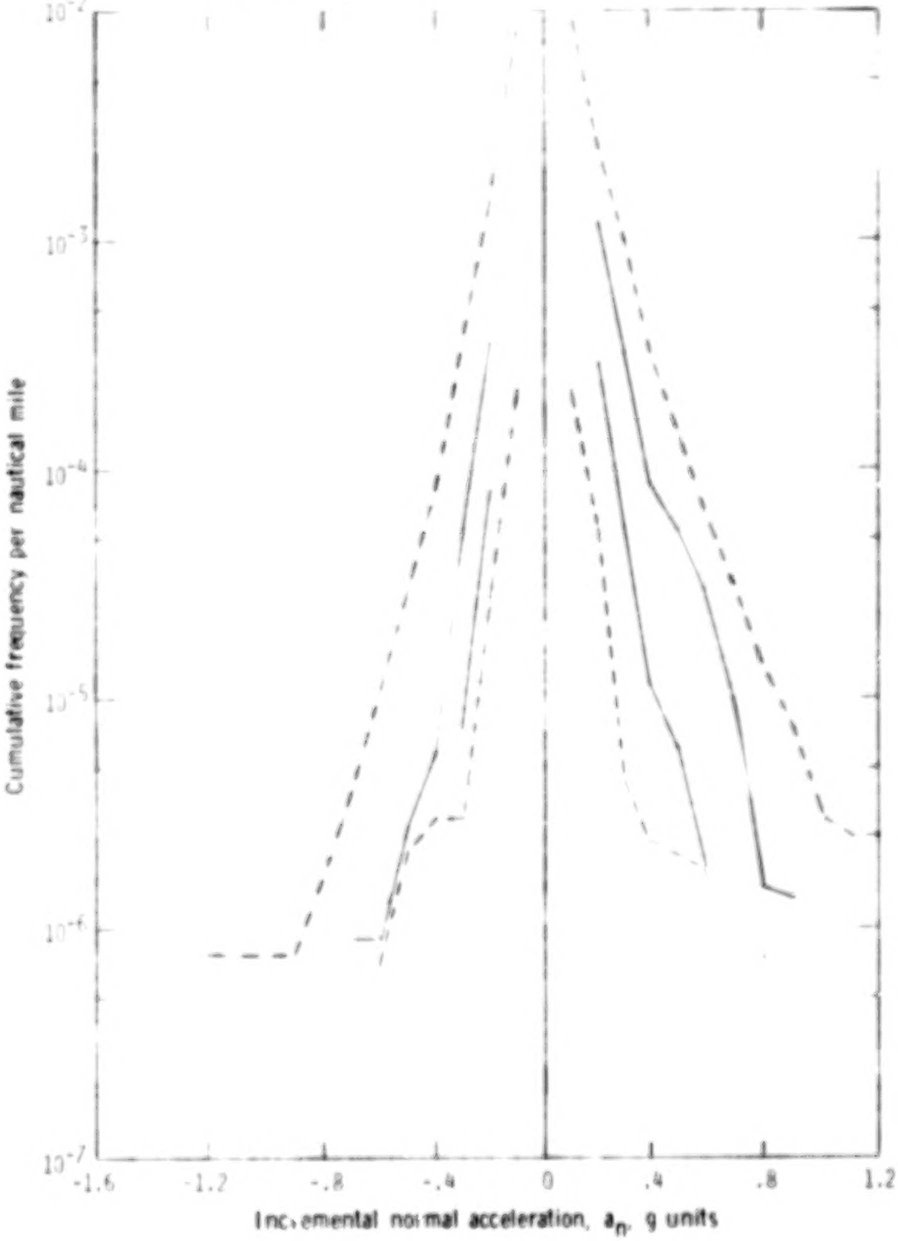
Figure 2.- Comparison of boundaries for in-flight acceleration data from one type of wide-body, long-haul jet transport, with those from three types of narrow-body, long-haul jet transports.



(b) Operational maneuver accelerations.

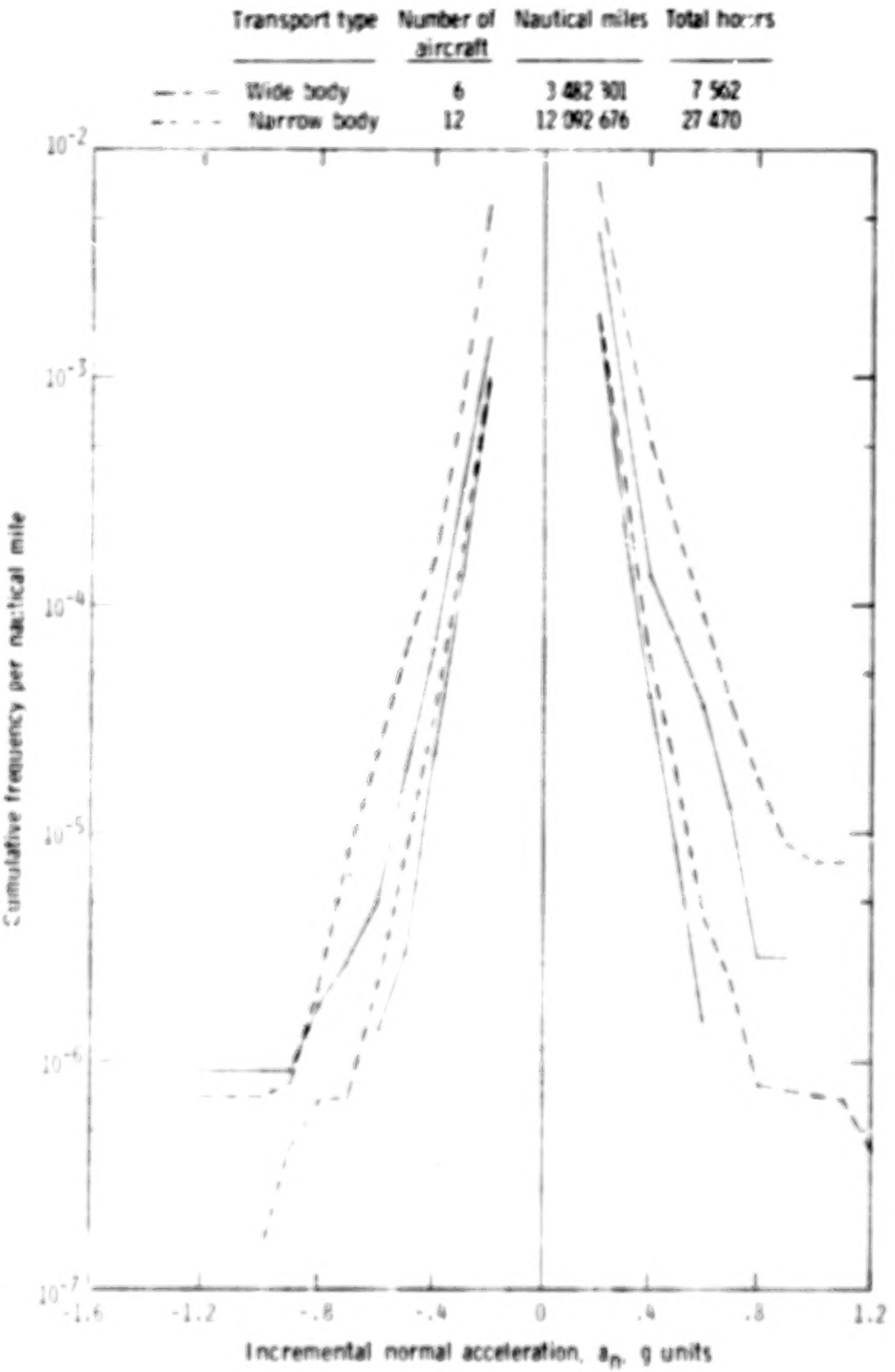
Figure 2.- Continued.

Transport type	Number of aircraft	Nautical miles	Total hours
Wide body	6	3 [illegible] 301	7 562
Narrow body	12	12 [illegible] 676	27 470



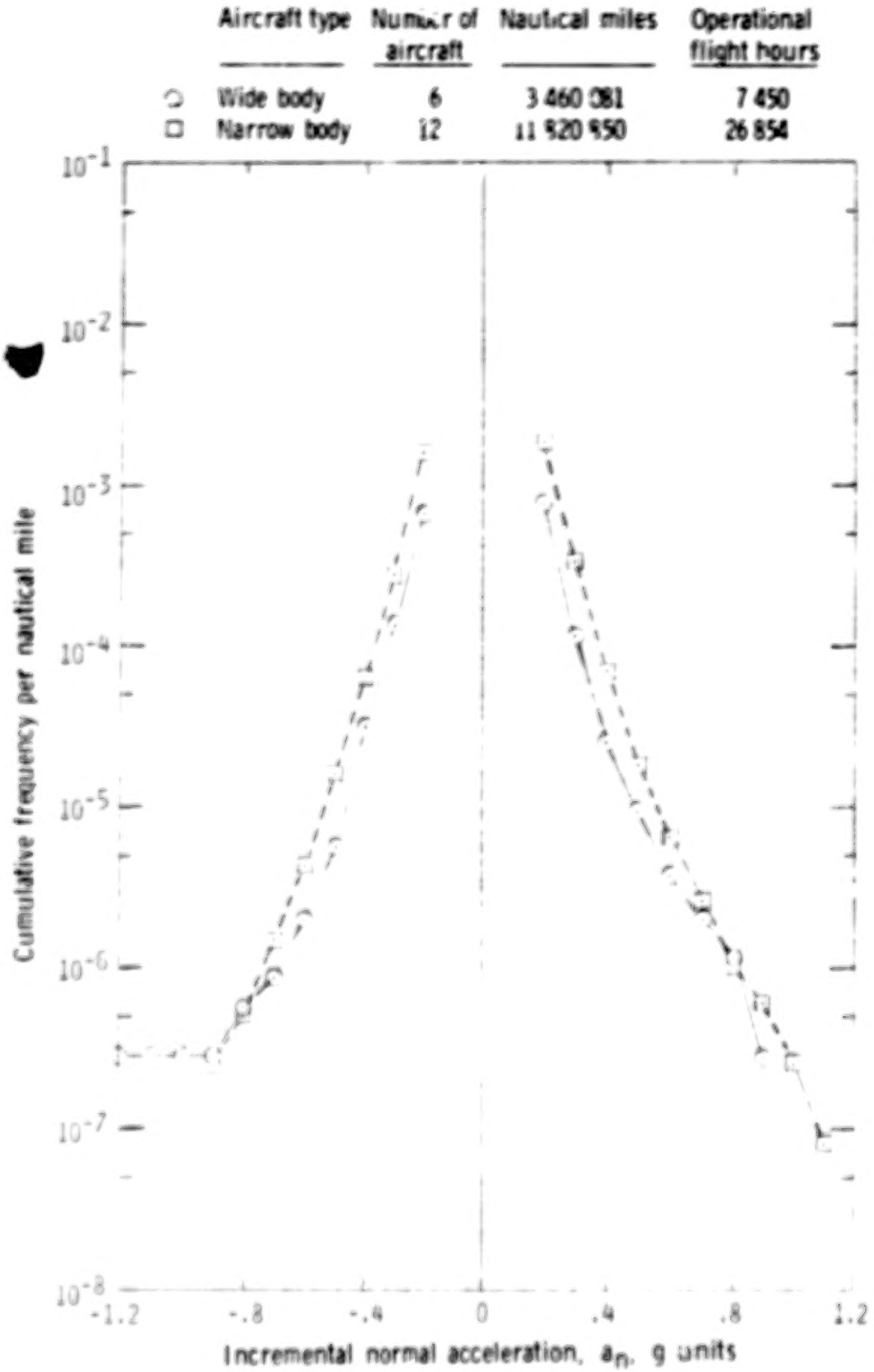
(c) Check-flight maneuver accelerations.

Figure 2.- Continued.



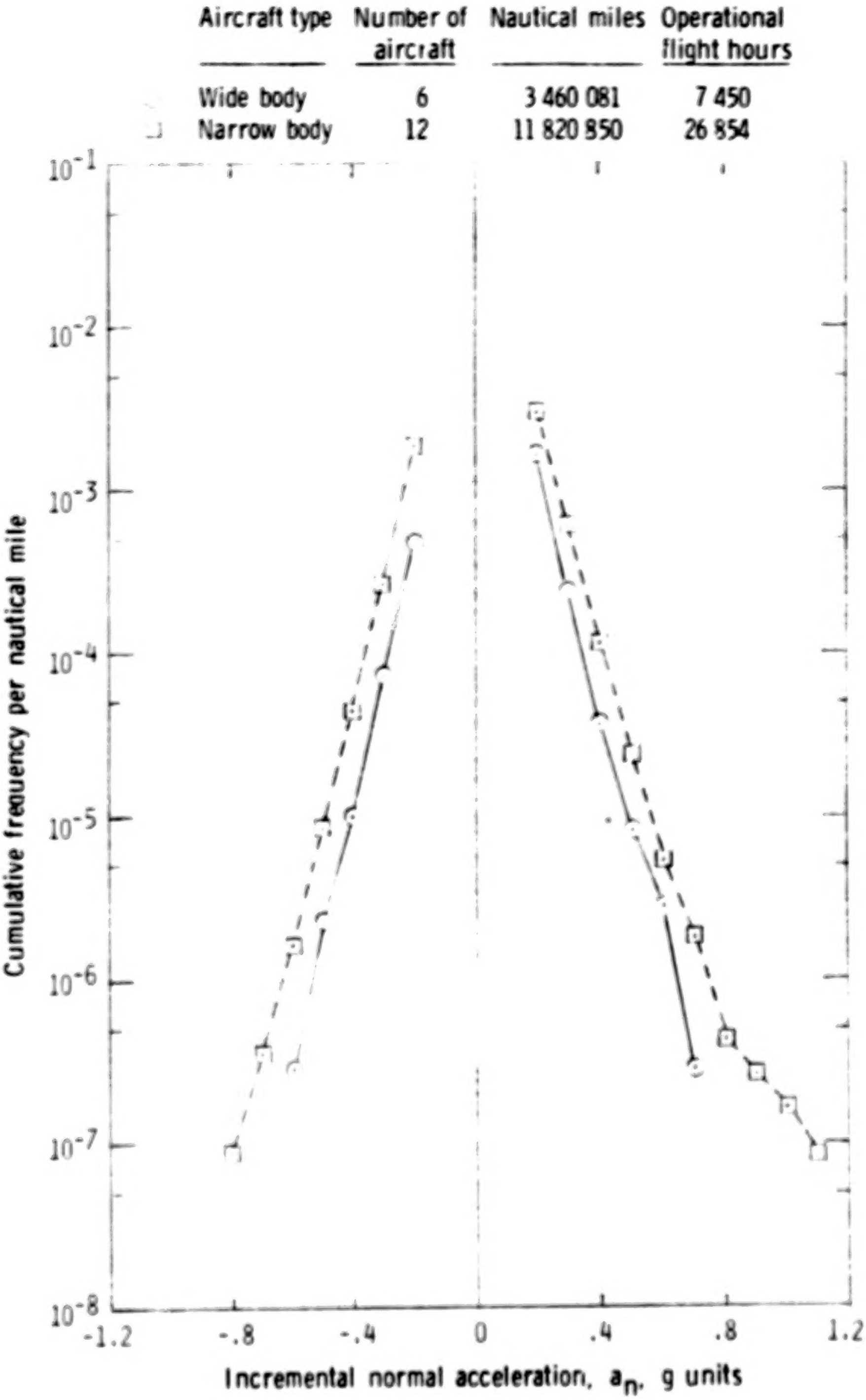
(d) Total in-flight accelerations.

Figure 2.- Concluded.



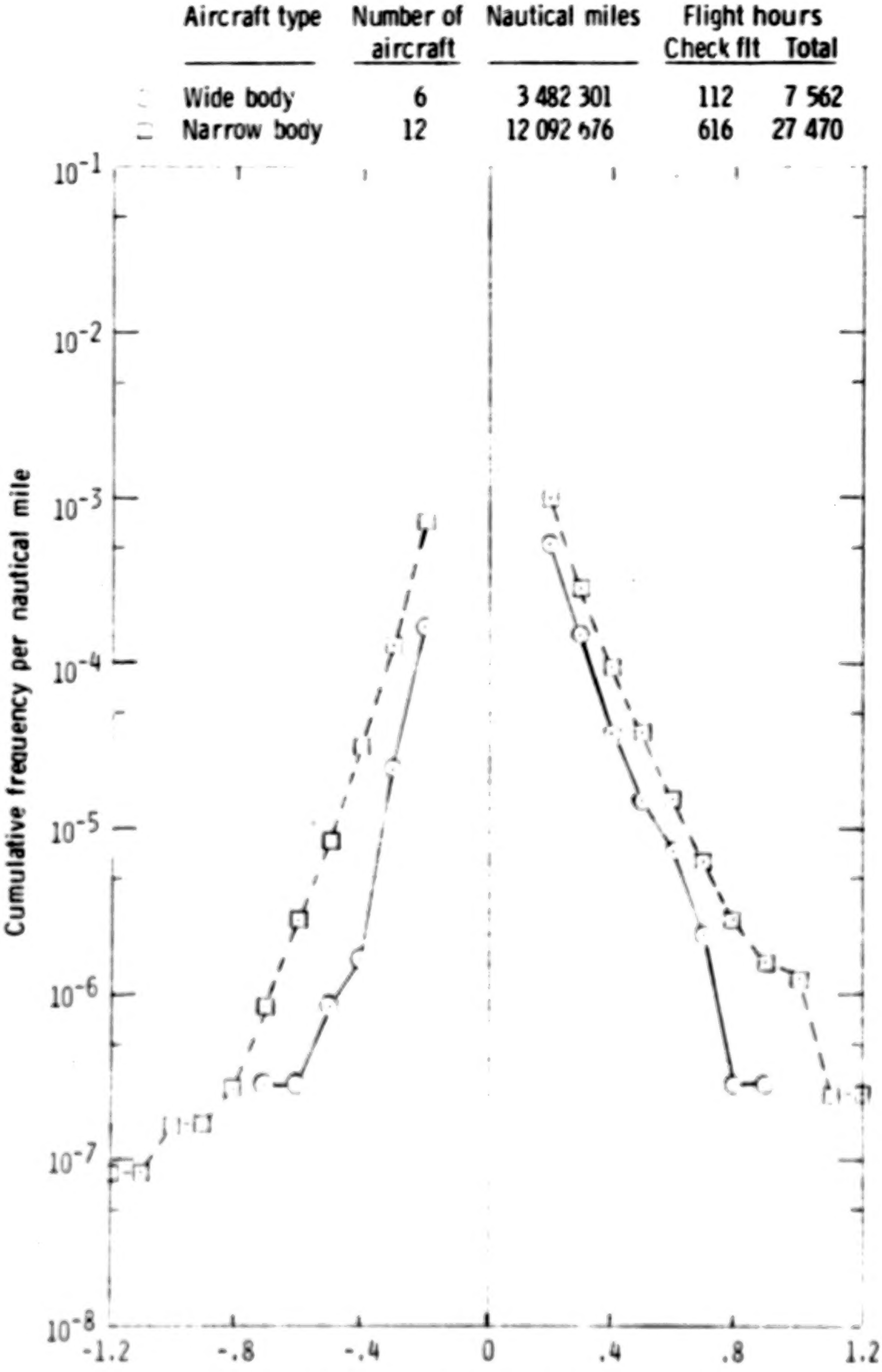
(a) Gust accelerations.

Figure 3.- Comparison of combined data for in-flight accelerations of wide-body and narrow-body long-haul jet transports.



(b) Operational maneuver accelerations.

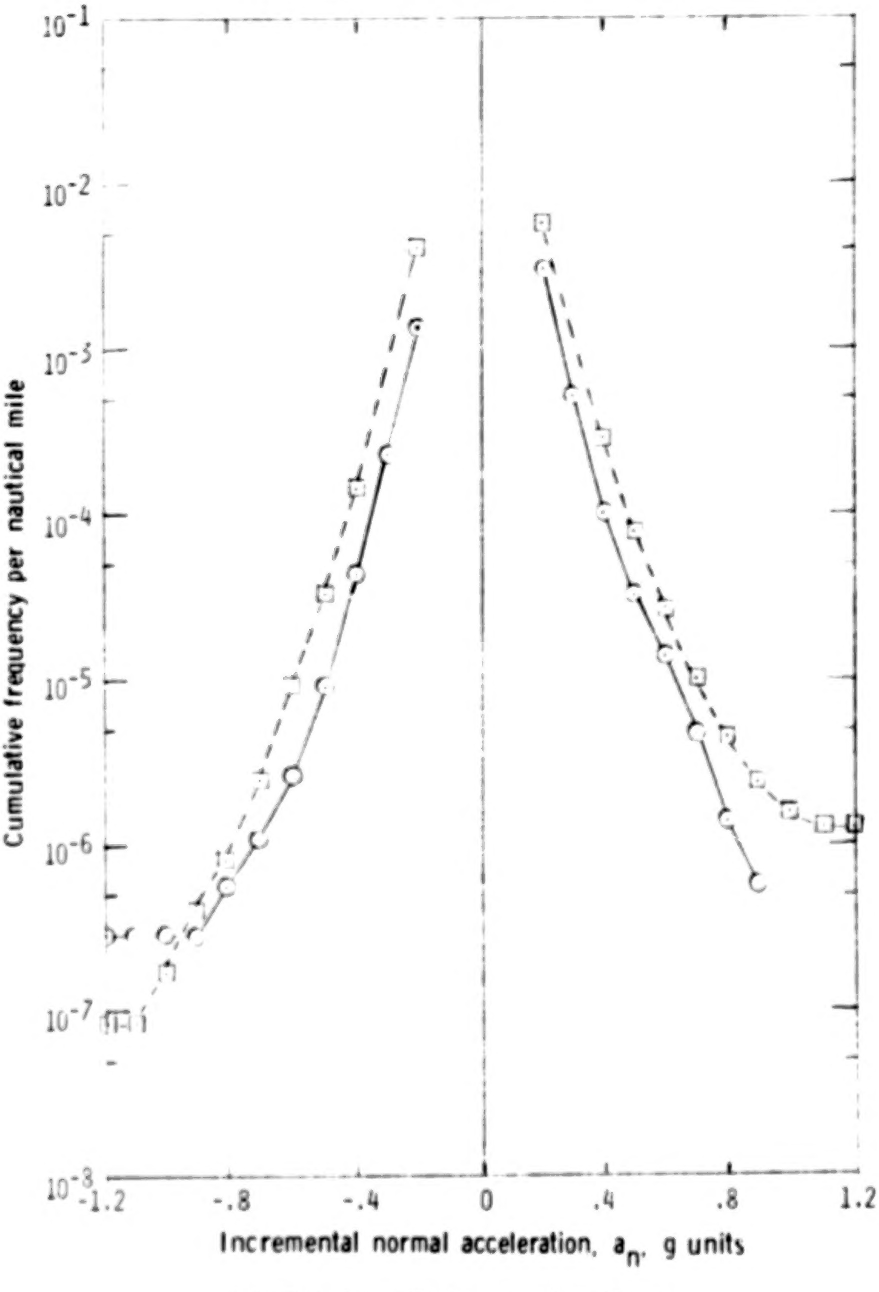
Figure 3.- Continued.



(c) Check-flight maneuver accelerations.

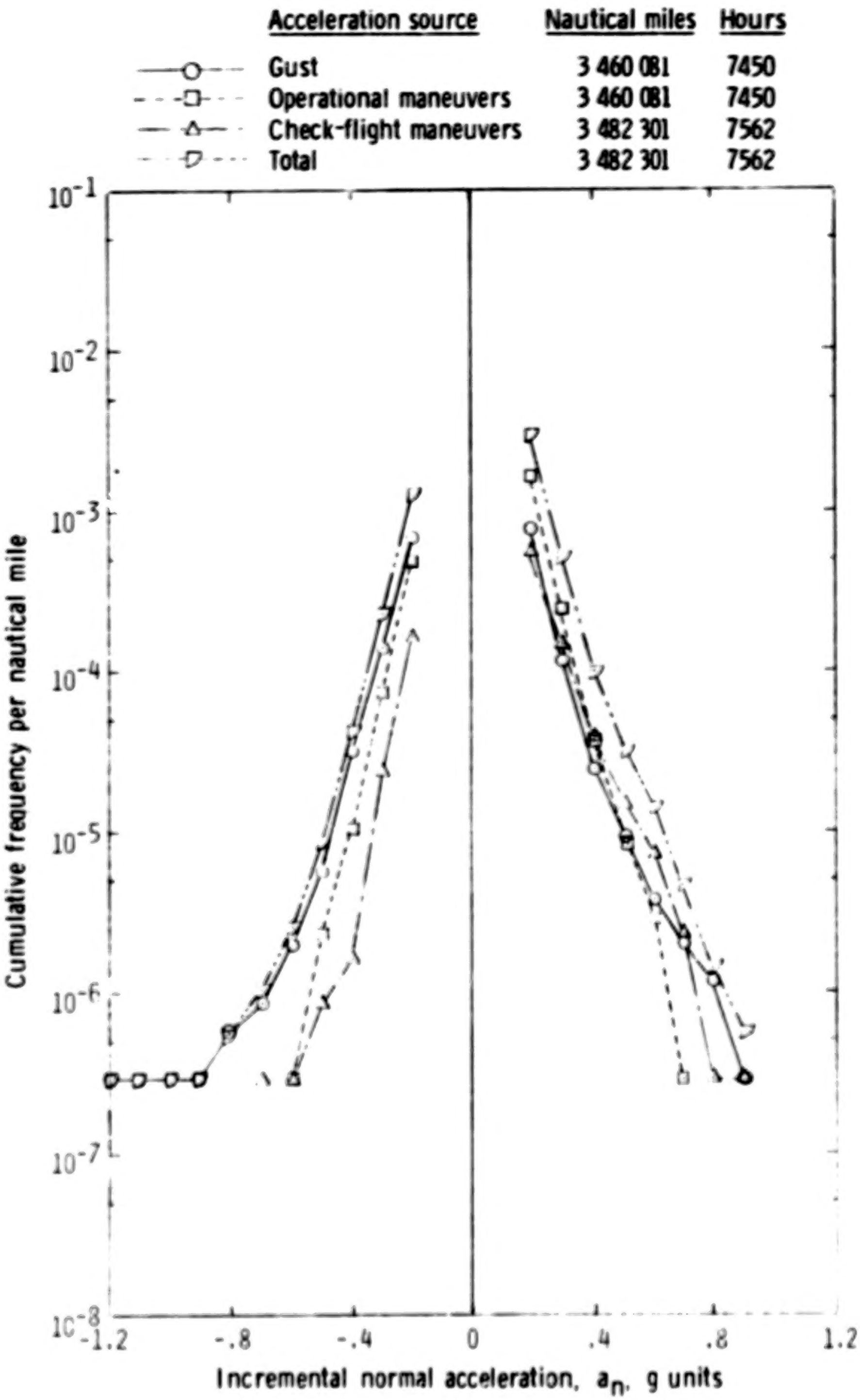
Figure 3.- Continued.

	Aircraft type	Number of aircraft	Nautical miles	Total flight hours
○	Wide body	6	3 482 301	7 562
□	Narrow body	12	12 092 676	27 470



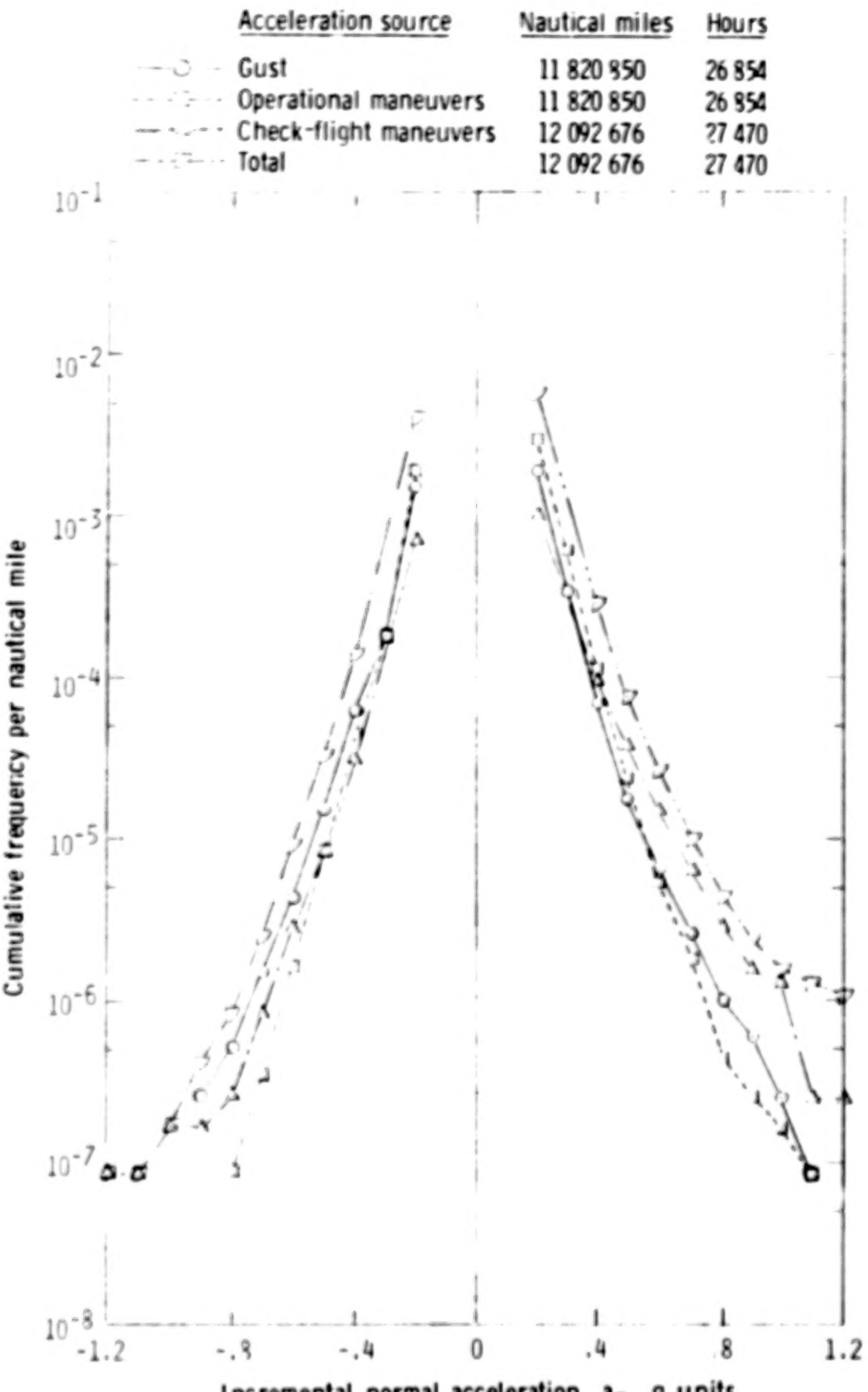
(d) Total in-flight accelerations.

Figure 3.- Concluded.



(a) Wide-body transports.

Figure 4.- Comparison of acceleration sources.



(b) Narrow-body transports.

Figure 4.- Concluded.

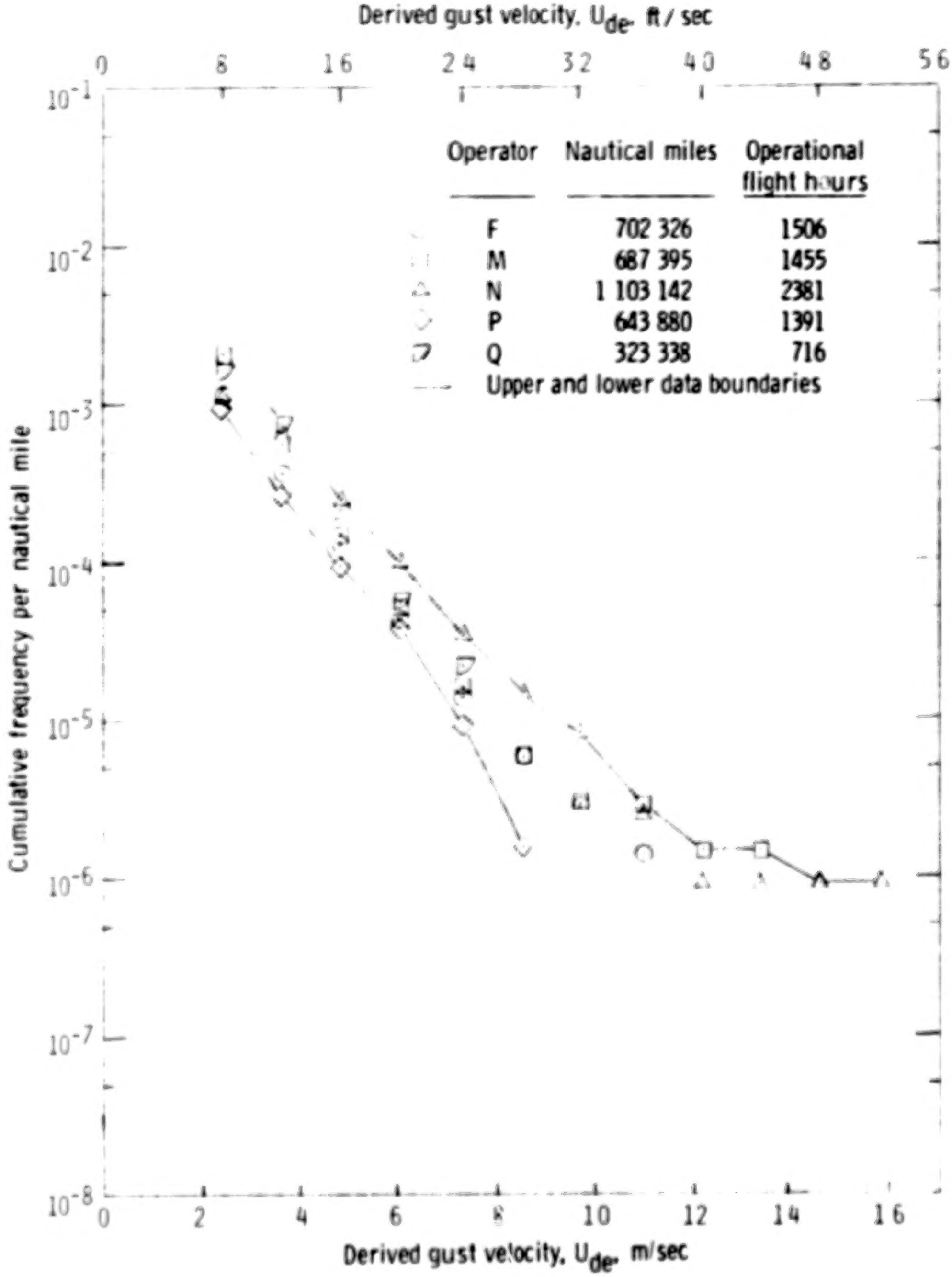


Figure 5.- Gust velocities, experienced by one type of wide-body, long-haul jet transport flown on international operations by three United States and two foreign operators.

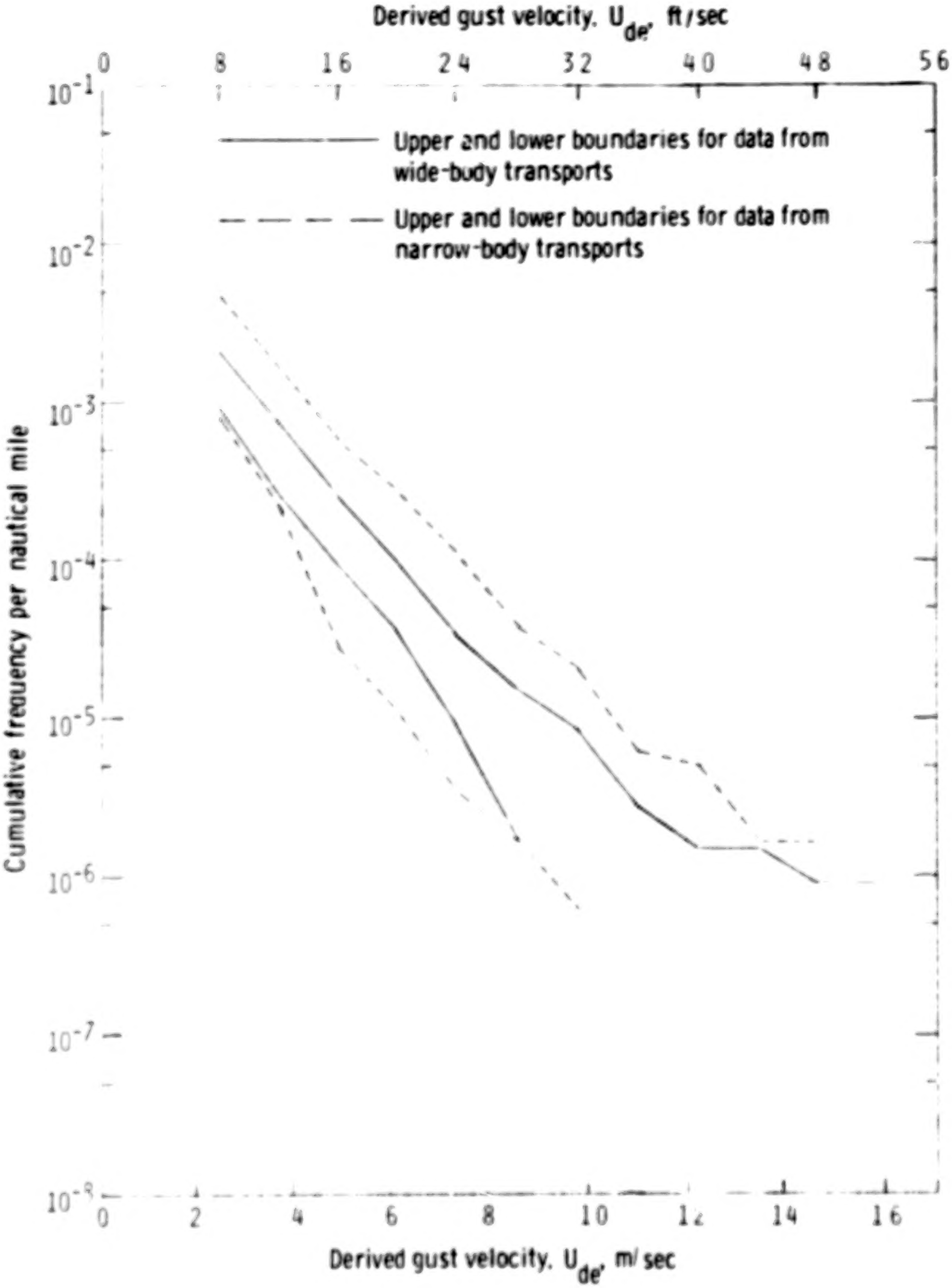


Figure 6.- Range of derived gust velocities experienced by one type of wide-body transport and three types of narrow-body jet transports.

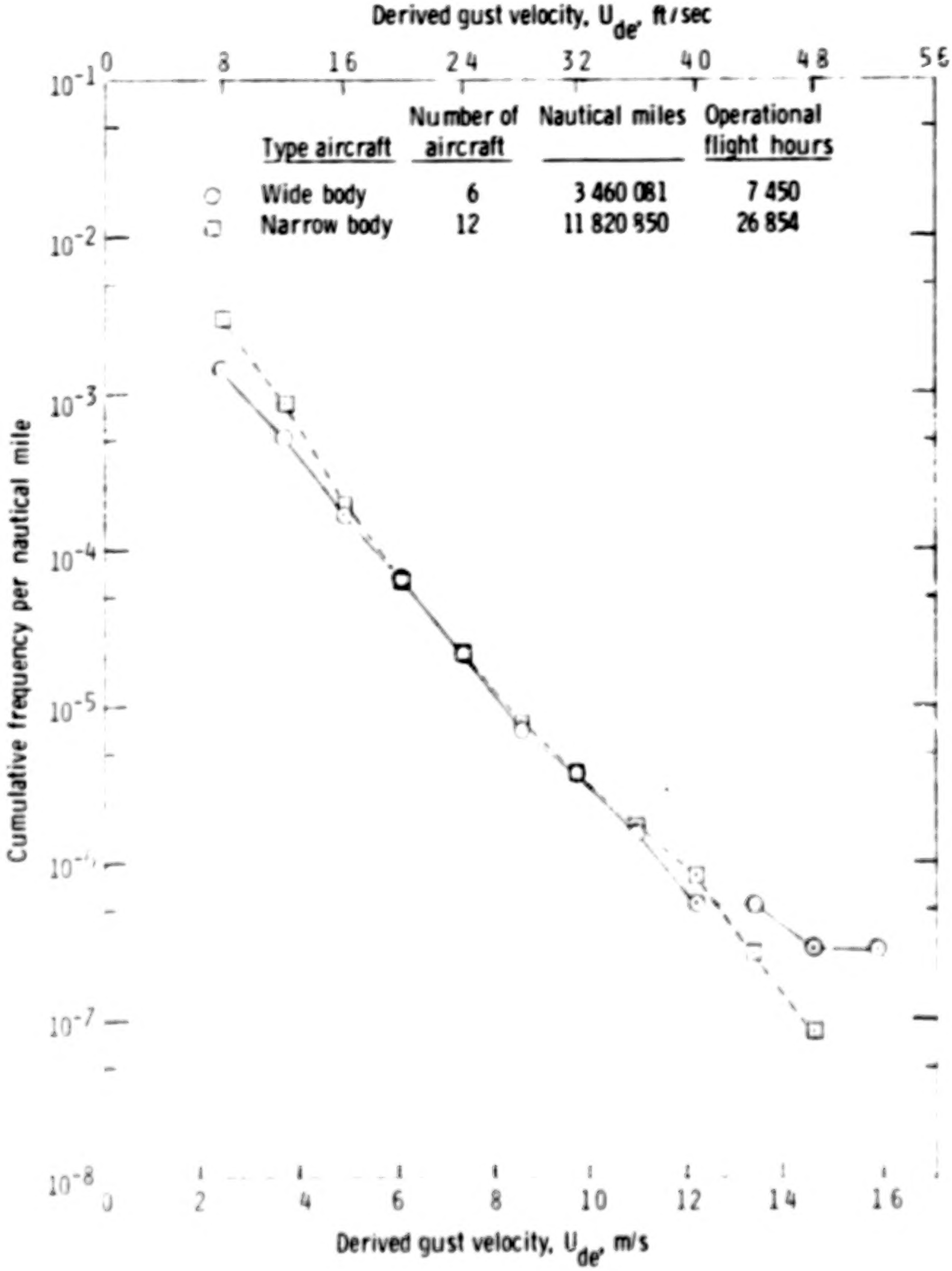
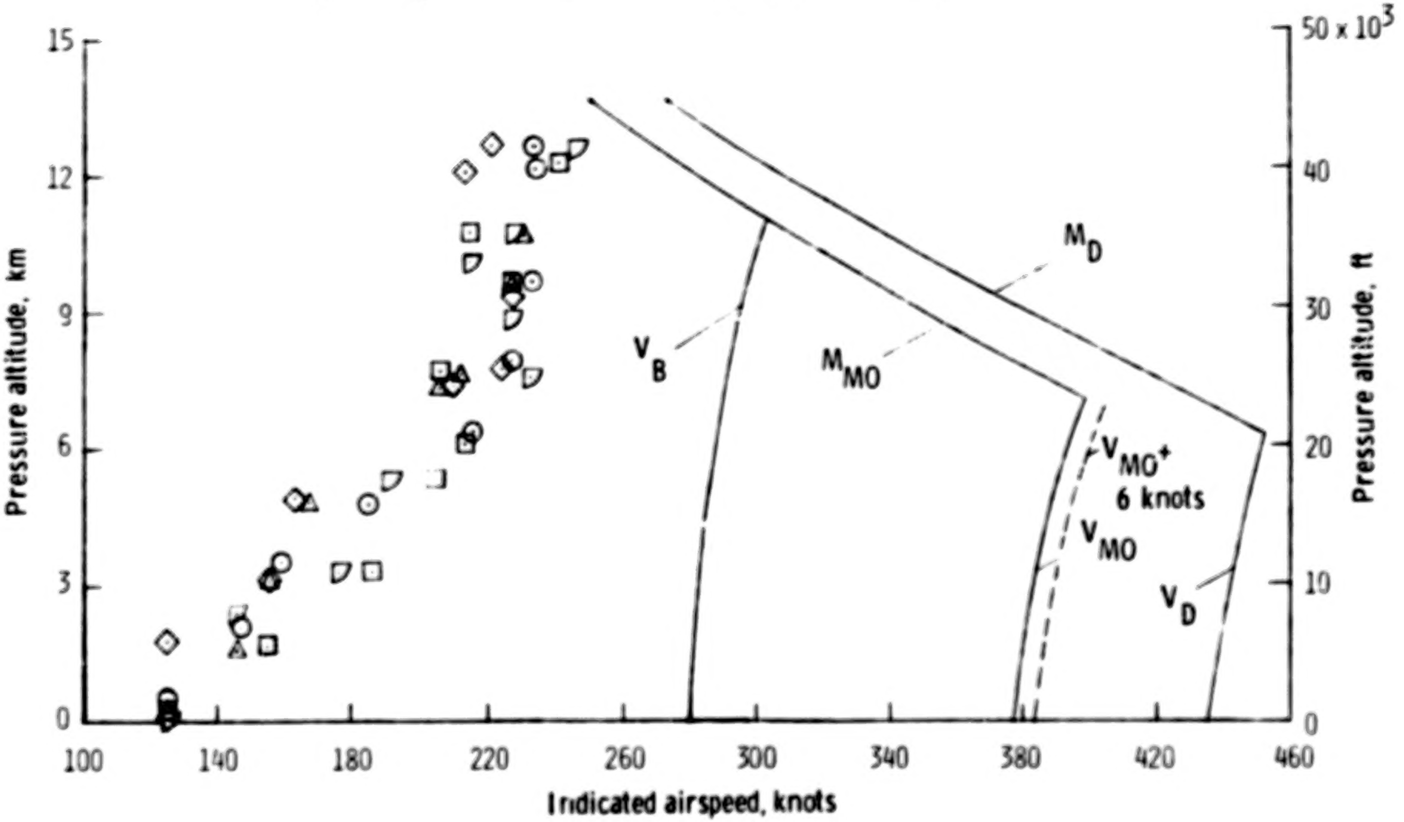


Figure 7.- Comparison of the combined derived gust velocities experienced by wide-body jet transports with those experienced by narrow-body jet transports.

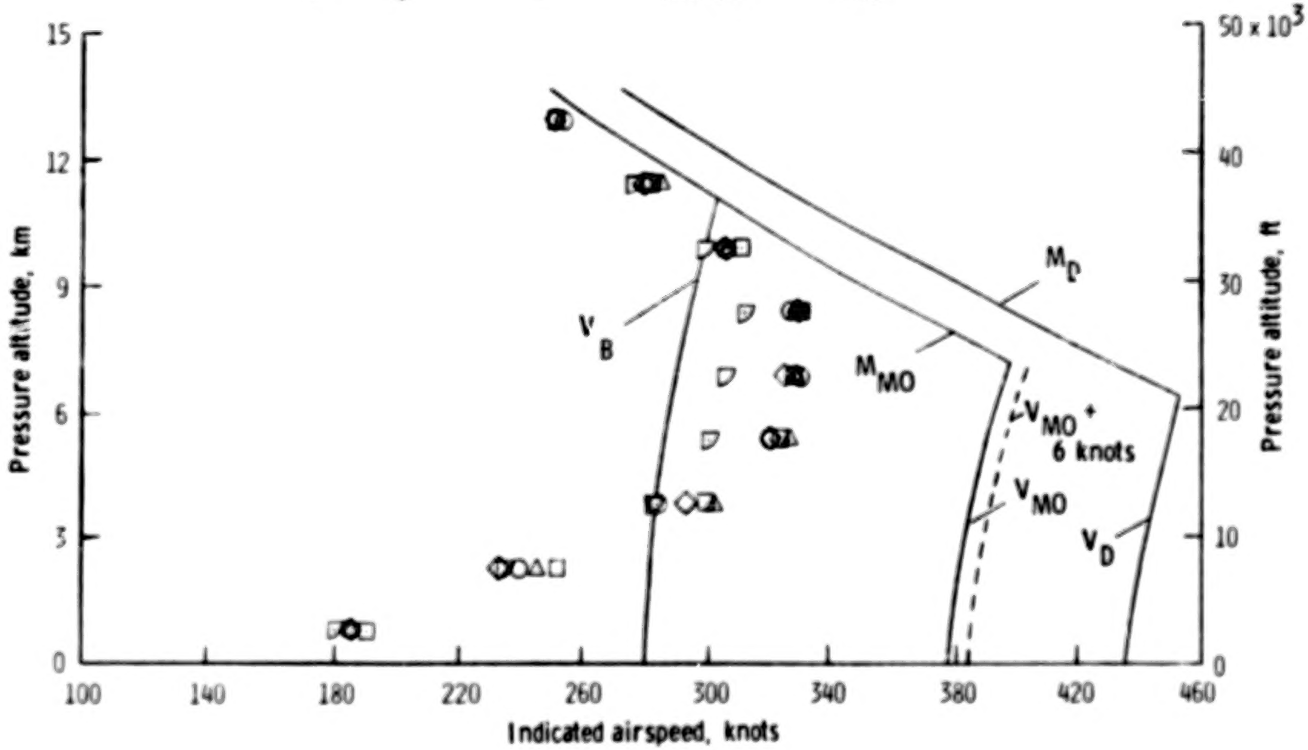
	Operator	Number of aircraft	Nautical miles	Operational flight hours
○	F	2	702 326	1506
□	M	1	687 395	1455
△	N	1	1 103 142	2381
◇	P	1	643 880	1391
◸	Q	1	323 338	716



(a) Minimum indicated airspeed.

Figure 8.- Variation of minimum, average, and maximum indicated airspeeds with altitude for one type of wide-body jet transport flown on international operations by three United States and two foreign operators.

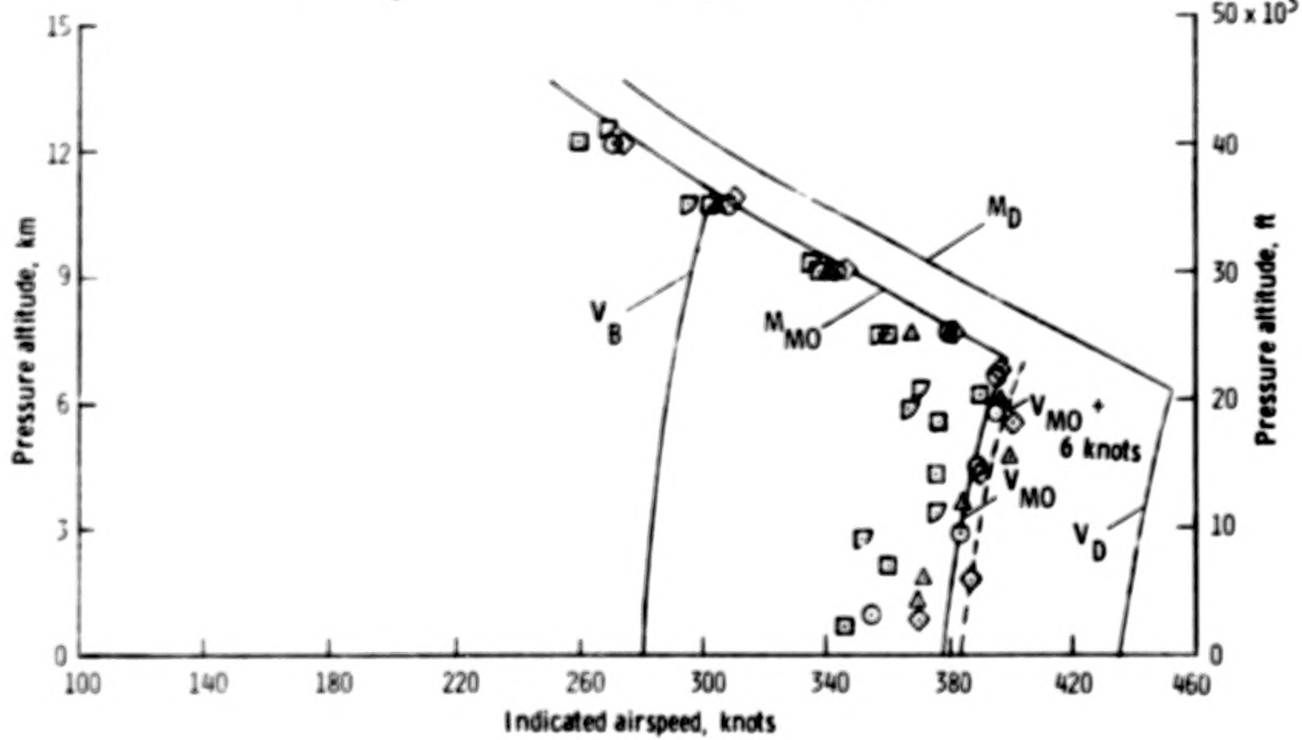
	Operator	Number of aircraft	Nautical miles	Operational flight hours
○	F	2	702 326	1506
□	M	1	687 395	1455
△	N	1	1 103 142	2381
◇	P	1	643 880	1391
◸	Q	1	323 338	716



(b) Average indicated airspeed.

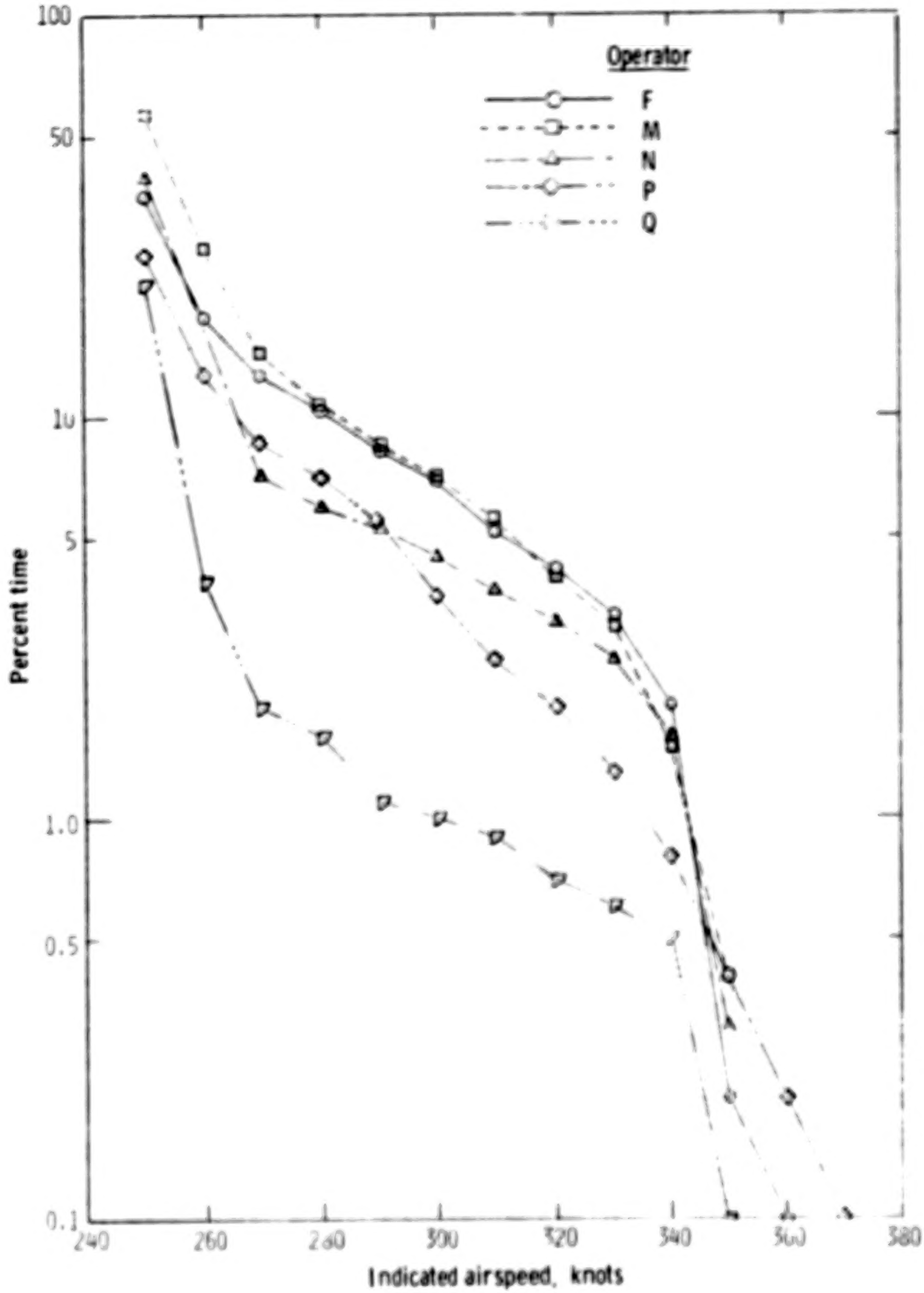
Figure 8.- Continued.

	Operator	Number of aircraft	Nautical miles	Operational flight hours
○	F	2	702 326	1506
□	M	1	687 395	1455
△	N	1	1 103 142	2381
◇	P	1	643 880	1391
▱	Q	1	323 338	716



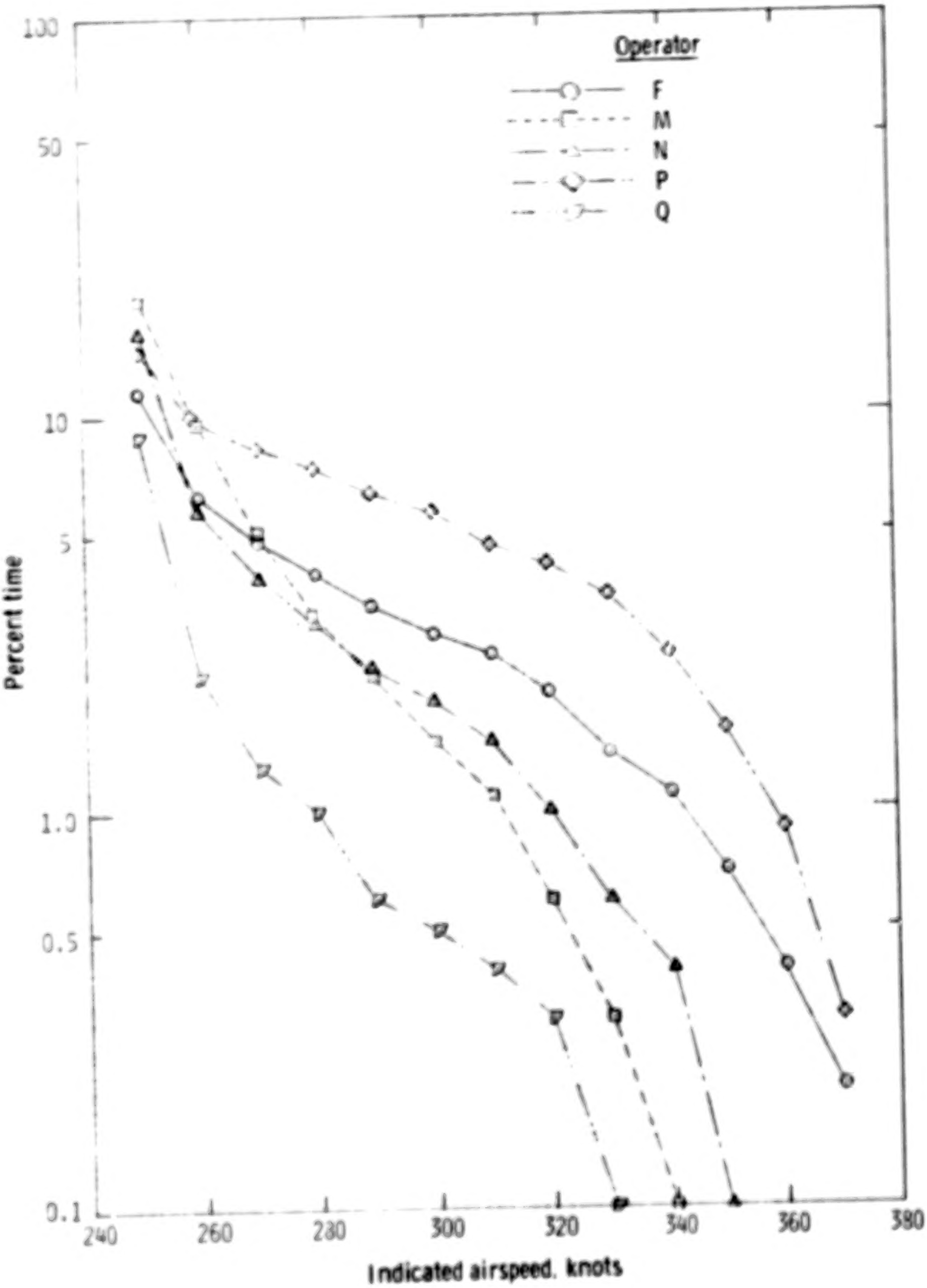
(c) Maximum indicated airspeed.

Figure 8.- Concluded.



(a) Climb.

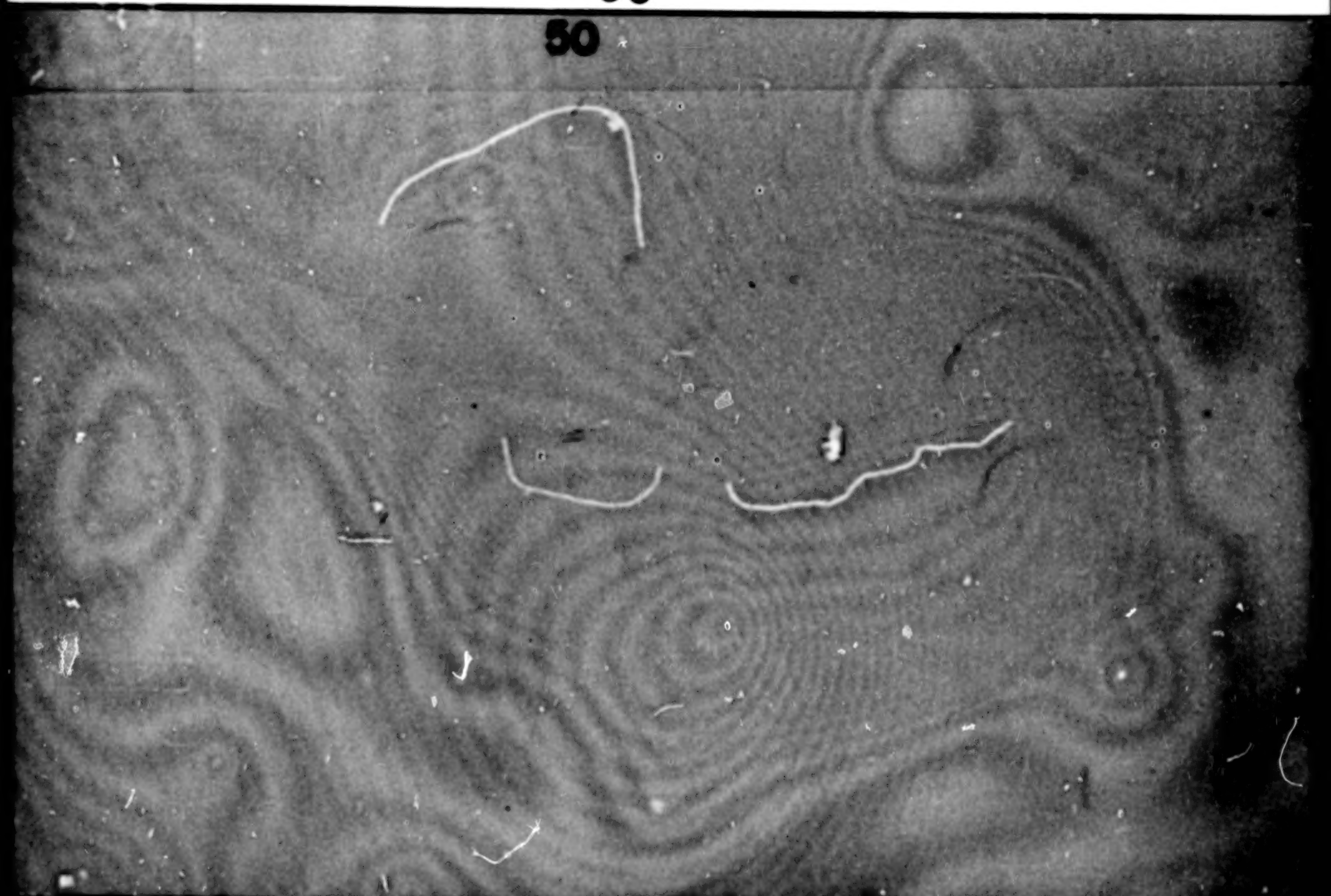
Figure 9.- Percent of time below 3 km (10 000 ft) in climb, and below 3 km in descent spent at airspeeds above 250 knots on international operations by three United States and two foreign operators.



(b) Descent.

Figure 9.- Concluded.

90



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